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Veterinary Anatomy of Domestic Mammals

Textbook and Colour Atlas

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Foreword

I was recently approached by my good colleague and friend, Dr. Horst König, to write a preface for the first English edition of his book co-authored with Dr. Hans-Georg Liebich. I consider it a great pleasure and honor for me to have the opportunity to endorse the "Veterinary Anatomy of Domestic Mammals, Textbook and Color Atlas" for Students and Practitioners, by Horst Erich König and Hans-Georg Liebich.

A short biographic sketch about the authors seems to be relevant. They came from different veterinary backgrounds but they share a passion for teaching anatomy and have attained similar high and prestigious academic standards of scholarly activity.

Dr. König was born in Romania in 1940, graduated from the Faculty of Veterinary Medicine in Bucharest in 1962 as a D.V.M. and M.S., and started his professional activity as a field veterinarian from 1962 to 1967. Assistant professor in Iasi, Romania, between 1967 and 1972, he became assistant professor in München from 1972 to 1980. He received his Ph.D. in 1978 and was accredited as a specialist in anatomy and surgery (Fachtierarzt für Anatomie und Fachtierarzt für Chirurgie) in 1980. The same year he was promoted as full professor in München. Chairman of the Department of Anatomy at the Faculty of Veterinary Medicine, University of Concepcion in Chile between 1987 – 1989, he was awarded the title of the "Best Professor of the Year" in 1988, and the title of honorary professor in 1989. Since 1992 he has been the Chairman of the Department of Veterinary Anatomy at the University of Veterinary Medicine in Vienna, Austria. In 1996 he was awarded the Medal "Jan Kolda" from Brno, the Czech Republic, and in 2001 the title of Doctor honoris causa (Dr. h.c.) from the Agronomic University "Ion Ionescu de la Brad" of Iasi, Romania. He is the author of six anatomy books (two of them in two volumes), the author of chapters in nine other books, has published 101 papers in refereed journals, and is a member in several national and international associations.

Dr. Liebich was born in Germany in 1942, graduated from the Faculty of Veterinary Medicine in München in 1969 as a D.V.M., and started his career as an assistant professor in histology in München. He received his Ph.D. in histology in 1973 and was promoted to professor extraordinary in 1979. In 1980 he was accredited as a specialist in anatomy (Fachtierarzt für Anatomie) and was promoted to full professor. In 1996 he became the Chairman of the Department of Anatomy in Munich. In 1997 he was awarded the Gold Medal of the Agricultural Academy of Wroclaw, Poland. Three titles of Doctor honoris causa followed in 1998 from the University of Veterinary Medicine in Vienna, Austria, in 2000 from the Faculty of Veterinary Medicine in Wroclaw, Poland, and in 2002 from the State University of Orenburg, Russia. Since 1999 Dr. Liebich has been the 1st Prorector of the Ludwig-Maximilians-University in Munich. He is the author of five books, chapters in four other books and has published 115 papers in refereed journals.

The "Veterinary Anatomy of Domestic Mammals, Textbook and Color Atlas" for Students and Practitioners, by Horst Erich König and Hans-Georg Liebich that I am presenting is a combination of a textbook and a color atlas. It is a remarkable work needed by students and practitioners alike.

The general and most important impression is that the book left aside unnecessary anatomical structures for the practitioners, and moreover for the students, who are not going to be trained as anatomists, but as veterinarians. For example, the description of the smaller vascular branches was deliberately omitted, the nervous system does not describe the differences between species, with some exceptions, etc. The students and the practitioners may find details in other sources of information, which are included in the references. In addition, the veins are described in the direction of blood flow, which is a very good concept in comparison to many contemporary books and the Nomina Anatomica Veterinaria.

Another general comment is the fact that this book is the first anatomy book published in recent years with colored illustrations.

The style of the text is vivid and original. The 681 pages, the impressive quality and number of illustrations (1,022 – 838 color) and the 53 tables speak for themselves. The text is well balanced, the tables very suggestive, including synoptic tables, and the illustrations are exquisite; they appear as in line drawings, half tone, black and white and color, showing microscopic, electron microscopic, and macroscopic anatomical images. I would like to emphasize that an anatomy book should be abundantly illustrated, with artwork which is easy to follow and clear. In their book, Drs. König and Liebich added radiographs, sections of fresh specimens, injections of joint cavities with plastic and colored substances,

casts showing corrosion of vessels, and schematic representations.

In each chapter the reader will find organogenesis, microscopic and macroscopic descriptions, and functional and clinically relevant relationships. All domestic mammals are included. Throughout the book, the international nomenclature is used, based on the 4th (last) edition of the Nomina Anatomica Veterinaria, 1994. An extended bibliography and an anatomical vocabulary at the end enable the reader to search other different sources of information for details.

I would like to inform the readers that the 2nd German edition of the book, in two volumes, was recently published, and that the book was translated into the Czech, Slovak, Portuguese and Spanish languages

The quality of paper and of printing of the illustrations is excellent, and I take this opportunity to congratulate the Publisher for this excellent and most recent publication.

I have the greatest pleasure and honor in wholeheartedly applauding Drs. König and Liebich for their remarkable work and contribution to education in the field of descriptive and clinical anatomy through their book of *"Veterinary Anatomy of Domestic Mammals, Textbook and Color Atlas"*.

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Preface

The university course of veterinary medicine challenges all students throughout the world on their way to becoming a veterinarian, from the first until the last day of their academic education, on the subject of "anatomy". As one of the fundamental courses, anatomy decisively forms the entry into this aspired professional field and plays a major role in imparting the knowledge required for later practice.

The publishers' aim with the revision and complete new structuring of a modern textbook has been to present the students and clinicians new ways of conveying knowledge. Thereby, great care was taken to combine the didactic character of a textbook with the informative character of a colour atlas. Furthermore, modern imagery and numerous newly designed schematic illustrations contribute considerably to the depiction of the anatomical material.

This modern concept of presenting information has undoubtedly proven its worth. The previously available first edition volumes of the "Anatomy of Domestic Mammals" in the German language were already followed by a second, revised and extended edition in the 3rd year.

It has therefore been deemed appropriate that a revised edition of such successful German publications should be issued in the English language. Also the efforts to support the future perspectives of an international harmonisation of veterinary education have found a global resonance. Consequently this book on "anatomy" has already been printed in Portuguese, Czech and Slovakian and now a translation into Spanish and Italian has also been begun with great vigour.

The participation of scientists from several European universities and veterinary faculties in the making of this textbook will be a further step in harmonising the education in the field of veterinary anatomy.

Over the past centuries, the learning material in the field of veterinary anatomy has increased immeasurably. The in-depth comparative-anatomical material and subject-specific details in particular have made it near to impossible for students to differentiate between important and less important facts during their studies and in practice.

Thus an important aim of this book is to aid student's comprehension while learning and during private studying of anatomical facts. Considering the large scope of material covered, the publishers therefore deemed it necessary to print a compact illustration of the anatomical material, which would be sensibly and effectively summarized into one volume of "anatomy".

Anatomy is not an isolated science. For that reason clinical relationships are referred to in the appropriate places, as well as the related areas of microscopic anatomy, histology, embryology or physiology. By taking into account the consistent overall view of structure and function as one unit, one is able to comprehend the organs and the organ systems in their original and systemic function and to recognize clinical changes. Under these aspects, in this newly revised edition as well, only the most important structures are needed for study and practice. These are discussed in detail, and the latest scientific findings are also included.

The basic concept of this "Veterinary Anatomy of Domestic Mammals" includes therefore in one volume the essential structural and functional facts on the locomotive apparatus, plus the internal organs of domestic animals, showing their close connection to the circulatory and the nervous system. Emphasis is also placed on the lymphatic and endocrine system, as well as the sensory organs, the skin and cutaneous appendages. In this way the facts are concentrated and by linking the content, a connection to the veterinary practice is undertaken. In so doing one avoided using detailed facts, in favour of a readable and illustratively presented text. The sensible supplementation of a large number of semi-schematic illustrations and colour photographs should also from a didactic perspective which contributes to enjoying the morphology.

A glossary of special anatomical words and a comprehensive subject index with relevant cross references to passages and a large number of tables assist the use of this book.

Our exceptional thanks goes to the translators of this book into English. Renate Weller, D.V.M. (The Royal Veterinary College, London, England), Mark Bowen, D.V.M. (The Royal Veterinary College, London, England) and Mark Dickomeit, D.V.M. (Nottingham, England) who, through their special anatomical knowledge, comprehensive experience, as well as their bilingual language talent have earned themselves special merit in the making of this book.

In the morphology the illustrations play a central role, so first of all we would like to say special thanks to Mrs. Eva Polsterer-Heindl, diplomate veterinary medical practioner (Vienna) as the scientific illustrator. Her task during the creation of the drawings did not only restrict itself to the

scientific precision and design, but also as a colleague included practical information in the illustrations, which are of especially great value for the students.

Beyond this my recognition goes to Professor Cordula Poulsen Nautrup, D.V.M. (Munich) and to Assistant Professor A. Probst, D.V.M. (Vienna) for the making and courtesy of using images, which were developed with the latest imaging methods and techniques. It was due to this cooperation that the concept of including modern methods of imagery into the anatomy and forging the link to clinic practice was achieved.

Also several students studying for their doctorate at the Institutes in Vienna and Munich brought in new scientific findings. Thus a large number of the preparations depicted here were produced during the completion of their doctorates. The large circle of these students may be thanked at this point for their competent scientific support.

A considerable number of preparations were produced by the veterinary surgeon Mr. A. Oliver (Barcelona) and the technician Mr. F. Hernandez (Barcelona). Professor Ana Carretero, D.V.M. (Barcelona) and Professor M. Navarro, D.V.M. (Barcelona) provided us with many preparations. They deserve a warm thank you.

Just as warmly we owe lecturer J. Maierl, D.V.M. (Munich) a special thanks for the active support in the making of a part of the colour images. Also our gratification goes to lecturer S. Reese, D.V.M. (Munich), who partook with untiring commitment in the digital processing of the extensive picture material. Beyond this we thank these two scientific colleagues for their professional and scientific support during the correction of the manuscript.

Our special thanks also goes to Mrs. Maria Koch (Vienna), who in her proven way took over the extensive writing of the text. An exceptional gratitude is owed to Mrs. Christel Schura (Munich), who with inexhaustible commitment decisively contributed to the aesthetic convincing structuring of text and images, as well as in the development of a printable version of the computer layout.

The few images that were modified from existing publications, re-drawn and supplemented are marked in the relevant places. The tables, replicated and enlarged are taken from the publications "Lehrbuch der Veterinär-Anatomie" of T. Koch and R. Berg, Gustav Fischer Verlag, Jena, Stuttgart (1992), and K.-D. Budras, W. Fricke and R. Richter, "Atlas der Anatomie des Hundes", Schlütersche Verlagsanstalt, Hanover (1996).

Most of the images of the original anatomical preparations were provided by the authors of the individual chapters. Further scientific images were presented to us by: Professor Sabine Breit, D.V.M., University Assistant K. Ganzberger, D.V.M., Professor W. Künzel, D.V.M., R. Macher, D.V.M. and Assistant Professor A. Probst, D.V.M. (Institute of Anatomy, Veterinary University, Vienna), Sybille Kneissl, D.V.M. (x-ray clinic, Chair Professor Elisabeth Mayrhofer, D.V.M., Veterinary University, Vienna) and Ana Carretero, D.V.M., Marc Navarro, D.V.M., Javier Perez, D.V.M. (Universidad Autonoma de Barcelona).

For the developing and preparing of anatomical specimens we would like to thank laboratory technician Mr. H. Dier and laboratory technician Mr. L. Hnilitza as well as the gentlemen L. Habeler, H.P. Jany und F. Lembacher (Institute of Anatomy, Veterinary University, Vienna).

Last but not least a special thanks goes to Mr. Dieter Bergemann, who through his further unlimited support and his personal effort played a vital role in the production and generous presentation of this book. Also we would like to thank the colleagues from the Schattauer GmbH, Mrs. Heidrun Rieble and Mr. Konrad Pracht, for their exceptional cooperation during the planning and development of this book.

Vienna and Munich
February 2004

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Contents

General introduction

H.-G. Liebich and H.E. König

Anatomy is the branch of **morphology** dealing with the form, structure, topography and the functional interaction of the tissues and organs that compose the body. The word "anatomy" is derived from Greek and literally means "cutting apart". The dissection of dead animals is still the most important and efficient method to study and comprehend anatomy. As the anatomical knowledge expanded histology, comprising micro-scopic anatomy and embryology, developed as a subdivision of the classic anatomy. The introduction of separate disciplines facilitates the understanding of the function of the entire body, especially for students.

Systematic anatomy has to do with "sytems", in other words with structures and organs that fulfil a common function. The respiratory system for example is responsible for the gaseous exchange, whereas the nervous system receives, translates, transmits and responds to stimuli. Thereby differences between the individual species can be compared, so that from an anatomical point of view the "systematic anatomy" in teaching also represents a **comparative anatomy,** preferably reduced to the domestic animals and poultry.

It is of great importance that the student acquires a profound knowledge of the systematic anatomy; from which he can then derive the overall connection of the structure and function of the animal body. Knowledge of the systematic anatomy is the essential foundation for the **topographic anatomy**, which describes the relative position and functional interaction of organs and structures of the various regions of the body. It presupposes a thorough working knowledge of systematic anatomy. Both, systematic and topographic anatomy, constitute the foundations of clinical practice.

Due to the tremendous amount of anatomical material available in the veterinary field, this book puts its emphasis on carnivores and the horse, since today these species require individual treatment. The anatomy of ruminants and pigs is only briefly discussed, with a few exceptions. Their anatomy can be studied in greater detail in more comprehensive books.

In chapter 12 "Organs of the cardiovascular system", the emphasis was put on the main vessels, while the description of the smaller branches was deliberately omitted. Veins are described in the direction of the blood flow. Description of veins in the retrograde direction, from the heart to the organs, as found in older anatomy books, can lead to misunderstandings regarding the location of valves, injection sites and sites for compression proximal to the region concerned.

The chapter regarding the nervous system does not describe the differences between the domestic species, apart from a few notable exceptions, since they are of minor importance in practice. A more detailed description is found in special literature.

The anatomical language of teacher and students must be precise and unambiguous. In 1968 a general agreement on the nomenclature of veterinary anatomy, which is based on Latin terms, the **Nomina Anatomica Veterinaria (NAV)** was introduced. The anatomical terms used in this book are published in the 4th edition of the NAV (1994).

Even though, in the clinical context, it is more useful for students to know the English expression, the Latin terms should not be neglected, since many clinical terms have a Latin or Greek origin. One example is the term "metritis", meaning inflammation of the uterus, which is a composition of the Greek word for uterus "metra" and the latin suffix "itis" meaning inflammation. No matter what language is used the terms should be informative and an aid to comprehension. If the meaning of an expression is unclear, we advise the student to look for the detailed scientific term in an anatomical or medical dictionary.

Directional terms and planes of the animal body

Certain descriptive terms are employed to indicate precisely and unambigously the position or direction of parts of the body. The most important anatomical terms are shown in Fig. 0-1 and listed with a short explanation in Table 0-1.

The body of an animal has major divisions, which are clearly distinguishable externally: the head (caput), the neck (collum), the trunk (truncus), the tail (cauda) and the limbs (membra).

Organs and organ systems of the animal body

Individual organs or organ systems are composed of cells or tissues with similar structure and function, which act syner-

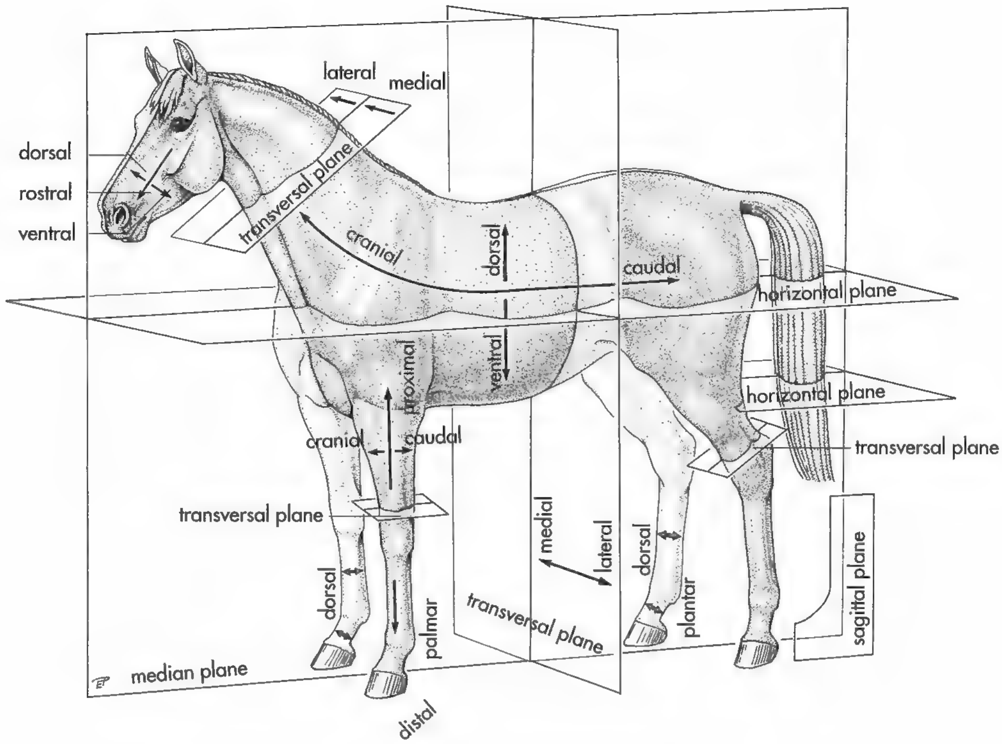

Fig. 0-1. Directional terms and planes of the animal body (schematic) (Dyce, Sack and Wensing, 1991).

gistically to fulfil the functions necessary for the survival of the whole organism (Table 0-2). Each organ system is composed of the parenchyma and the stroma. The cells of the parenchyma are responsible for the function of the organ (e.g. hepatic cells, renal cells, glandular cells), whereas the stroma consists of connective tissue, which contains the blood vessels, lymphatics and nerves and is essential for the nutritional and regulatory support of the organ. Some systems, such as blood and lymphatic vessels or the nervous system supply different organs and influence their functional and structural character considerably. Systematic anatomy deals with each of these organ systems in detail. They are listed in Table 0-2.

The domestic mammals, which are the major topic of veterinary anatomy are classified taxonomically as dog (canis lupus f. familiaris), cat (felis sylvestris f. catus), pig (sus scrofa f. domestica), ox (bos primigenius f. taurus), sheep (ovis ammon f. aries), goat (capra aegagrus f. hircus) and horse (equus przewalskii f. caballus). In addition to the domestic mammals, veterinary anatomy also comprises poultry and uses chicken (gallus gallus f. domestica) as the most common example.

Locomotor system

The locomotor apparatus is a **complex organ system,** with its central function to form and maintain the shape of the individual body and the locomotion of body parts or the whole organism. These mechanical functions are performed by the major elements of the locomotor system, the skeleton and the muscles.

The skeleton is composed of individual elements, the bones (ossa), cartilages (cartilagines), ligaments (ligamenta) and the joints (articulationes), forming the framework, which supports and protects the soft tissues of the body. The skeleton **(systema skeletale)** constitutes the passive part of the locomotor system, whereas the musculature **(systema musculare)** is termed the **active part,** since it contributes actively to the locomotion of the body. Both systems form a functional unit, complemented by the nervous and circulatory systems and the metabolism of both systems that is regulated by hormones.

Skeletal system (systema skeletale)

Osteology (osteologia)

Precursors of the skeleton

All components of the skeleton develop from the **embryonic mesoderm**, which divides in very early stages into an embryonic, reticular and fibrous tissue. These tissues consist of **cells** (e.g. fibrocytes), **fluid-filled intercellular spaces** and **fibrous components** (collagen or elastin). During development the fibrous component increases and is transformed into tendons,

Tab. 0-1. Directional terms and planes of the animal body.

Term	Meaning	Usage
cranial	towards the head	trunk and tail, limbs proximal to the carpus and tarsus
rostral	towards the nasal apex	head
caudal	towards the tail	head and trunk, limbs proximal to the carpus and tarsus
dorsal	towards the back	trunk, head, limbs distal of the carpus and tarsus
ventral	towards the belly	trunk, head
medial	towards the centre	head and trunk
lateral	towards the side	head and trunk
median	in the middle	trunk, head and limbs
proximal	towards the trunk	limbs and other body parts located close to the trunk or projecting away from the trunk
distal	awayfrom the trunk	limbs and other body parts located at a distance form the trunk or projecting away from the trunk
palmar	towards the palm of the hand	forelimbs distal of the carpal joint
plantar	towards the sole of the foot	hindlimbs distal of the tarsal joint
axial	towards the axis of the digits	digits
abaxial	away form the axis of the digits	digits
external	located outside	body parts and organs
internal	located inside	body parts and organs
superficialis	located near the surface	body parts and organs
profundus	located in the depth	body parts and organs of the head and trunk
temporal	towards the temporal bone	eye
nasal	towards the nose	eye
superior	above	eyelid
inferior	below	eyelid
apical	towards the apex	nose and toe
oral	towards the mouth	head
median plane	virtual plane dividing the body in two equal part	
paramedian-plane	any plane parallel and located near to the median plane	
sagittal plane	any plane parallel and located distant to the median plane	
dorsal plane	any plane parallel to the dorsal surface	
transverse plane	any plane perpendicular to the long axis	

Tab. 0-2. Organ systems.

Name	Primary function
Outer skin	Protective covering of the animal body
Skeleton and joints	Supporting framework of the body
Musculature of the skeleton	Locomotion
Digestive system	Food intake, mastication, chemical digestion, excretion and absorption
Respiratory system	Oxygen supply, elimination of carbon dioxide and production of sound
Urogenital system	Excretion and reproduction
Circulatory system	Transport and exchange of substances
Nervous system	Regulation, transmission, reaction in response to external stimuli
Organs of sense	Reception of external stimuli
Endocrine glands	Regulation of cell functions by hormones
Immune system	Response to infection

Fig. 0-2. Section of the digits in a young cat during chondral ossification (magnification 20 x, Goldner staining).

ligaments and fascia at genetically determined locations. (Details are found in histology or embryology textbooks).

The transition between the primordial tissues of the skeleton of the trunk and limb starts in early stages of embryological development and results in structural and functional changes of the primary components, which lead to the development of the major components of the skeleton, bone and cartilage. Both components originate from mesenchymal precursor cells, the chondroblasts and osteoblasts, forming the chondrocytes and osteocytes, which produce collagenous fibres and intercellular matrix.

Development and growth of cartilage

Cartilaginous tissue is characterised by the structure of its **intercellular substance,** which is composed of **collagenous fibres** with a high content of **glycosaminoglycans.** This special architecture is responsible for the high strength of cartilage and for the ability of cartilage to bind water, which results in an increase in elasticity and plasticity.

Cartilaginous tissue has no blood vessels or nerves, but is supplied by diffusion from the subchondral bone, surrounding soft tissue and synovia. The quality of the embedded fibres determines the type of cartilage, hyaline, fibrous or elastic cartilage. In the adult, **hyaline cartilage** forms the articular surfaces of synovial joints (cartilago articularis), the costochondral junctions (cartilago costae), parts of the laryngeal (cartilago laryngis), tracheal (cartilago trachealis) and bronchial (cartilago bronchialis) walls. **Elastic cartilage** constitutes part of the epiglottis, the external ear and the hoof. **Fibrocartilage** form the menisci in the stifle joint and the articular disc in the temporomandibular joint. Some cartilages ossify in later life, such as the costal cartilages or the menisci in cats.

The **formation of cartilage** (chondrogenesis) starts out from mesenchymal tissues, remnants of which still surround the cartilage in later stages of development (perichondrium). Perichondral **fibroblasts** become **chondroblasts,** which produce the major components (water, collagenous or elastic fibres and glycosaminoglycans) of the cartilage matrix.

Growth of cartilage takes place primarily by the increasing numbers of chondroblasts in the perichondrium, which leads to an **apposition** of more cartilage from the **outside**. Another way of cartilage growth is achieved by mature chondrocytes **within** the cartilage matrix, which continue to **divide** and form a new matrix substance.

Development and growth of bones

During foetal development the mesoderm is transformed to create the **cartilaginous structure of the primordial skeleton,** which determines the shape of the foetus. These cartilage precursors grow rapidly by mitotic cell divisions and soon come to resemble the final form in broad outline, until they are replaced by the osseous skeleton.

In the later stages of foetal development changes take place, which result in the destruction of the major part of the cartilaginous skeleton and its replacement by **osseous tissue**. This process by which bone is formed within pre-existing cartilage is called **endochondral (secondary or indirect) ossification** (Fig. 0-2).

The resulting woven bone is immature and again broken down to be replaced by the mature lamellar bone. The major part of the bony skeleton in the adult animal (e.g. the skeleton of the spine and the limbs) develops by endochondral ossification.

Bone deposition begins at definite **centres of ossification** from which it extends to the periphery. This process of ossification starts in the middle of the foetal period of development and continues long after birth, in some bones the completion of these processes is not complete until adulthood. Unossified cartilaginous structures are visible radiographically in juvenile animals and can lead to misinterpretation as radiographic abnormalities.

Another type of bone development is the **intramembraneous (direct, primary) ossification** by which bone forms directly in mesenchymal tissue, without cartilaginous precursors. Bones, which undergo intramembraneous ossification are designated as membrane bones (e.g. bones of the face and roof and sides of the skull and the periosteal collar of the long bones). The process of fracture healing is similar to intramembraneous ossification and shows the same stages of differentiation.

Function and structure of the bony skeleton

Bone and cartilage form the supporting **framework of the body.** They ensure locomotion, protect the soft tissue organs of the thoracic and pelvic region, as well as the central nervous system by encasing the brain and spinal cord. Bone is considered to be a **haemopoietic organ**, since it includes the red bone marrow, which produces red blood cells and several kinds of white blood cells. In the adult it stores fat. It also serves as a **store** of calcium, phosphate and other minerals (Fig. 0-3). Thus the skeleton has three different major functions: **support, protection** and

Fig. 0-3. Sagittal section of a long bone after maceration **(A)**, sagittal section of a long bone in a fresh state with articular cartilage and red bone marrow **(B)**.

metabolic function. The structure of a specific bone reflects the role it plays in life and the bony skeleton in general largely influences the **architecture of the body.** The structure of a bone adapts to the mechanical requirement that it is subjected to by changes in metabolism. This adaptation is achieved by continuous resorption and deposition of osseous material.

Every bone is submitted to these adaptive processes throughout life. Bones respond to changes in stress or strain after a short time through remodelling processes. The bones of the limbs, the spine or the pelvis undergo more intensive remodelling than the bones of the skull. Compact bone is developed in direct ratio to the stress to which the bone is subjected. Therefore it is thickest in the middle part of the shaft (diaphysis) of long bone and thins out toward the extremities (epiphyses). Local areas of increased thickness are present where there is increased tension from ligaments or tendons.

The function of a bone is also influenced by the soft tissue membrane, the **periosteum,** which invests the external surface of the bone. The periosteum is absent at places, where tendons and ligaments attach and it does not cover the articular surfaces. It is composed of two layers, the **outer protective fibrous layer** (stratum fibrosum) and the **inner cellular osteogenic layer** (stratum cambium). The inner layer includes a high number of sensory nerve fibres and a network of blood and lymphatic vessels, which supply the bone. This layer has the potential to produce bony tissue throughout life. It plays an important role for the growth of bones, physiological remodelling and fracture repair. Sometimes this layer overreacts to stimuli and produces osseous bulges (exostoses) at the site of injury. One major function of bone is the **storage of calcium and phosphorus.** The spongy bone of several bones contains depots of calcium which can easily be mobilised, when required for the maintenance of circulating calcium, which is important for body functions. The calcium and phosphorus metabolism is regulated by endogenous and exogenous mechanisms.

The parathyroid hormone of the parathyroid gland activates bone-destructing cells, the osteoclast, causing an increase in calcium concentration in the blood. It also slows down the excretion of calcium by the kidneys and, together with vitamin D_3 (1,25-Dihydroxycholecalciferol), enhances the absorption of calcium in the intestines.

Calcitonin is produced by the C-cells of the thyroid and acts as an antagonist to the parathyroid hormone. It activates osteoblasts, resulting in a higher rate of bone deposition and hence reduction in circulating calcium concentrations. Bone growth is also positively influenced by the somatotrophic hormone (STH), the adrenocorticotrophic hormone (ACTH) and the thyreotrophic hormone (TSH), as well as by male and female sex hormones.

Intramembraneous ossification (osteogenesis)

The key-process of intramembraneous ossification is the transformation of mesodermal cells into bone cells of several types. In the first stage undifferentiated mesenchymal cells become **preosteoblasts,** which are the precursor cells for the bone producing osteoblasts. **Osteoblasts** synthetise the organic components of the bone matrix. During the process of intramembraneous ossification osteoblasts surround themselves with a deposit of **non-calcified ground substance (osteoid),** which mineralises transforming the cells into **osteocytes** (Fig. 0-4 and 5). The

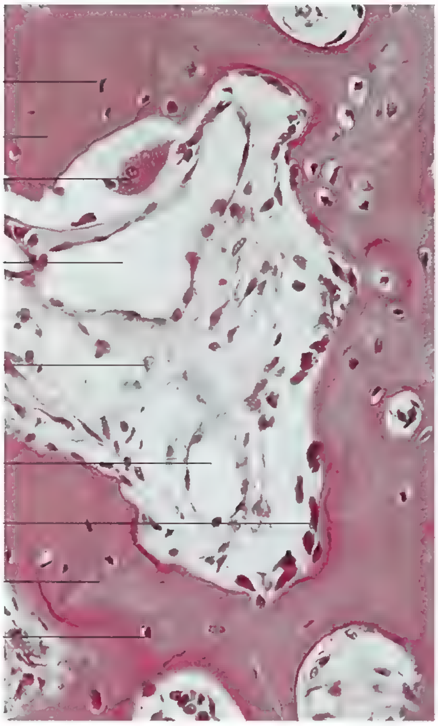

Fig. 0-4. Intramembraneous ossification with central capillary within soft tissue including osteoblasts and osteocytes (magnification 400 x, hematoxylin and eosin staining).

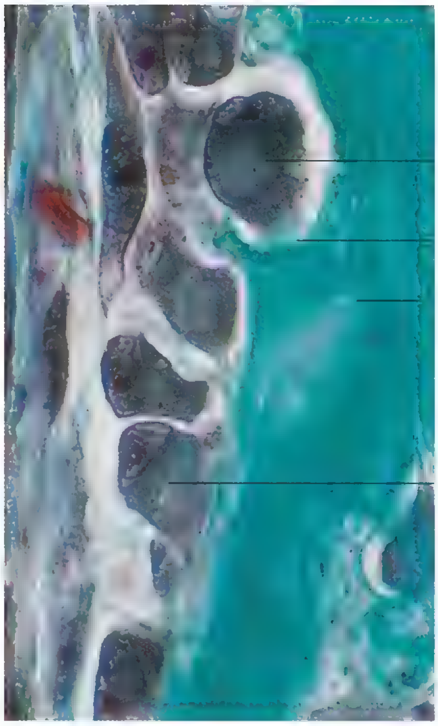

Fig. 0-5. Intramembraneous ossification with osteoblasts, osteoid and ossein (magnification 400 x, Goldner staining).

organic ground substance of the bone matrix is composed mainly of type I collagen fibres (90 %) with glycosaminoglycans, proteoglycans, chondroitin-4-sulphate, chondroitin-6-sulphate and keratan sulphate. The organic matter forms a scaffolding for the deposition of the inorganic material. The proteins of the collagen fibres form, together with lipids (5–10 %), one third of the dry weight of the bony tissue.

Mineralisation of bone is achieved by the deposition of inorganic material within the organic ground substance. Bone mineral is mostly calcium phospate (85–90 %), calcium carbonate (8–10 %), magnesium phosphate (1.5 %) and calcium fluoride (0.3 %). Removal of the organic matter of bone, by heat does not change the shape of the bone, but reduces the weight by about one third and makes the bone very fragile. Decalcification with acid renders the bone soft and pliable.

Chondral ossification (osteogenesis)

Chondral ossification relies on hyaline cartilage, which forms precursor models in the pattern of adult bones. It also provides the basis for the **longitudinal growth of bone.** Chondral ossification can be subdivided in **endochondral and perichondral ossification** (Fig. 0-6 to 9).

Perichondral ossification is similar to intramembraneous ossification. Chondroblasts of the perichondrium differentiate directly into osteoblasts **(primary ossification).** The transformation of soft tissue into bony tissue starts in the middle of the diaphysis and results in the formation of a **tubular bony sheath,** the periosteal collar about the centre of the shaft. The process of ossification progresses towards each extremity. The perichondrium thus becomes the **periosteum** of the bone. The gradually extending periosteal collar inhibits the metabolism of the hyaline cartilage resulting in mineralisation of the cartilage matrix.

At the same time, the cartilage is invaded by blood vessels, extending from the periosteal collar. These vessels are accompanied by chondroclasts, which destroy the calcified matrix. Capillaries and soft tissue essential for the nutrition of the new bone fill the resulting spaces. Osteoblasts are provided with the blood vessels and start to form new bone after they have reached the medullary cavity **(endochondral ossification).** The continuous process of destruction and reconstruction of the bone matrix results in a spongy texture of the bone, in which the cavities finally unite to form the **primary medullary cavity.**

In the late stages of foetal development the **secondary multi-chambered medullary cavity** develops by transformation of the soft tissue into **hemopoietic tissue,** the **red bone marrow** (medulla ossium rubrum), which is responsible for the production of red blood cells and some white blood cells. In the adult animal the red bone marrow of the diaphysis is gradually replaced by fat (medulla ossium flava), which is again transformed into gelatinous marrow in senile animals (medulla ossium gelatinosa). The bone marrow of the epiphyses however remains a hemopoietic organ throughout life. The original cartilage of the primordial skeleton persists only as two plates, the **epiphyseal or growth plates** (metaphyses) that intervene between the diaphysis and the epiphyses. These are of special significance in the process of endochondral ossification, since they are responsible for the subsequent longitudinal growth. The periosteal collar encloses the

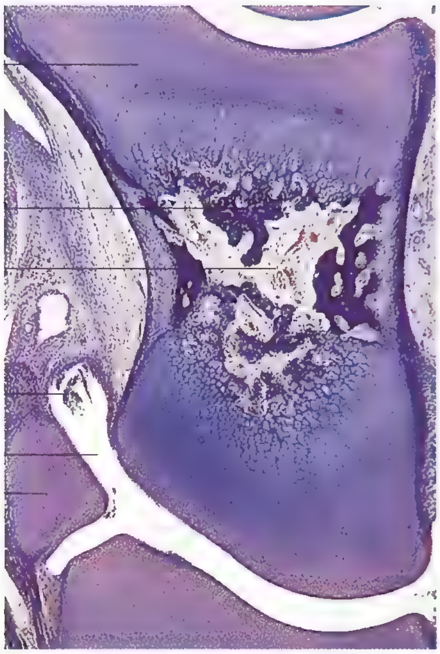

Fig. 0-6. Section of developing middle phalanx of a fetal horse (magnification 25 x, Azan staining).

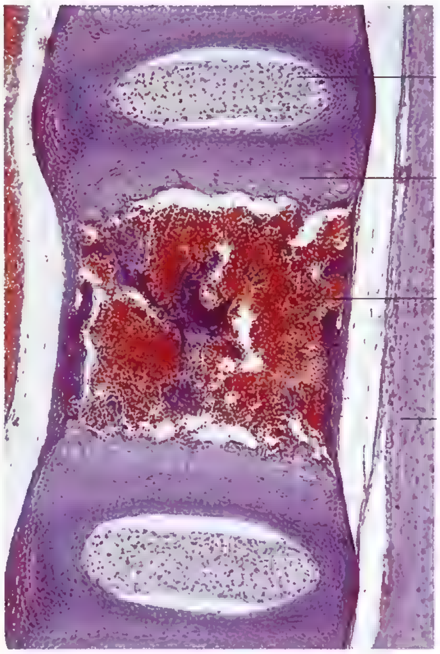

Fig. 0-7. Section of developing vertebra (magnification 25 x, Azan staining).

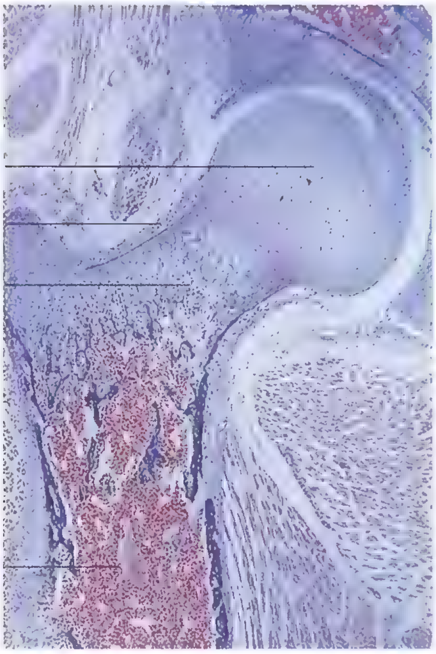

Fig. 0-8. Section of developing femur (magnification 20 x, Azan staining).

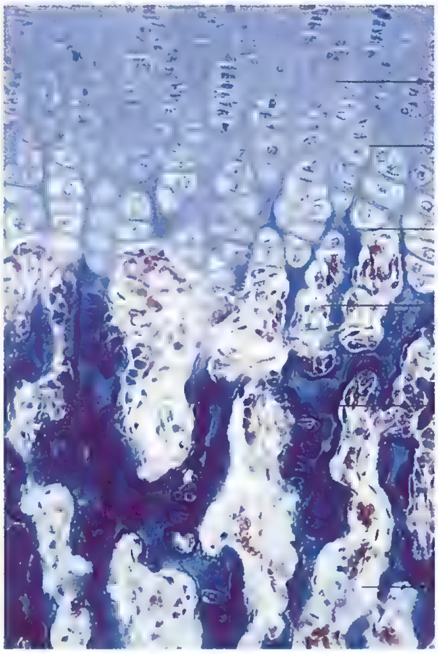

Fig. 0-9. Section of the epiphysis of a long bone demonstrating endochondral ossification (magnification 40 x, Azan staining).

bone and inhibits the growth of cartilage radially. At the same time the **chondrocytes hypertrophy** and form columns. The growth of the cartilage is the key-process of the **longitudinal growth** of the bone. Transformation of the cartilage occurs in several zones:

The chondrocytes juxtaposed to the epiphyseal endplate have a diffuse pattern and do not divide **(zone of resting chondrocytes).** This is followed by a zone of **proliferative chondrocytes,** characterised by stacks of thin, wedge-shaped cells that are actively mitotic. In the zone of **maturing chondrocytes** cell and lacunar size increase progressively and the cells form obvious columns. Mechanical influence upon the growth plate probably accounts for this structure. In the next zone, the chondrocytes start to degenerate, characterised by an increase in volume and a reduction in intercellular substance **(zone of hypertrophied chondrocytes).** In the final stage the intercellular matrix becomes impregnated with minerals and ossification is completed **(zone of calcified**

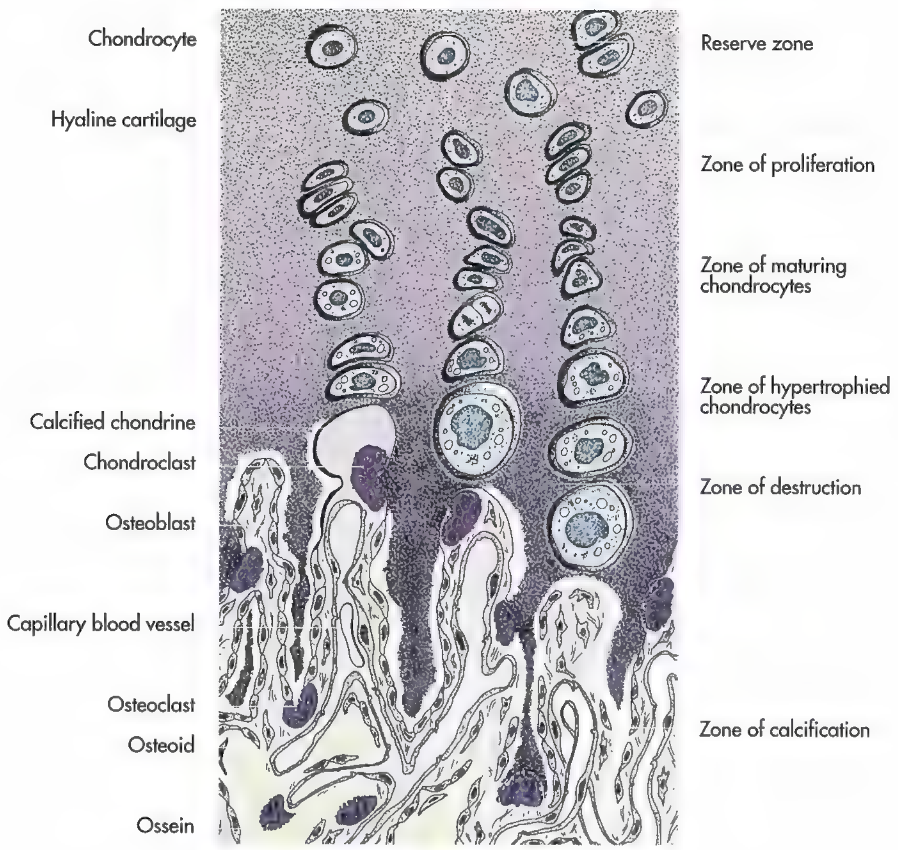

Fig. 0-10. Diagram of the epiphysis of a long bone demonstrating endochondral ossification (schematic) (Liebich, 2004).

cartilage). Chondroclasts, which have the capacity to destroy and remove cartilage are transported, by blood vessels from the medullary cavity, to the site of ossification, where they complete the destruction of the cartilage **(zone of destruction),** (Fig. 0-9 and 10). The same vessels provide secondary osteo-blasts, which produce ground substance (osteoid), which results in the replacement of the woven bone by lamellar bone.

Forms of bony tissue

There are two different types of bone tissue, **woven bone** (os membranaceum reticulofibrosum) and **lamellar bone** (os membranaceum lamellosum). The woven (fibrous, immature) bone is thought to be phylogenetically the older form and consists of ossified soft tissue. It is produced during foetal development of new bone and after birth replaced by the more complex lamellar bone. Some bones, such as the ossous labyrinth of the ear, the external acoustic meatus and in long bones at sites, where large tendons or ligaments attach, remain woven bone throughout life.

Lamellar (mature) bone is characterised by collagen fibres, which are arranged in parallel and concentric layers, called lamellae. This form of bony tissue is the most common in the adult animal and forms the long bones as well as the short and flat bones. It is composed of cylindrical units, called **osteons** or referred to as the **Haversian system.**

Each **osteon** consists of a central vascular channel **(Haversian canal),** surrounded by concentrically arranged layers of collagen fibres and calcified matrix **(Haversian lamellae).** Each layer is orientated at a different angle to the previous layer. Osteons are joined by transverse bony structures, resulting in a stress and strain resistant construction (Fig. 0-11 to 13).

Bone cells are located between the concentric lamellae surrounding the Haversian canal. They extend cytoplasmatic processes within **bony channels** (canaliculi ossei), which radiate in all direction to anastomose with those of adjacent cells. Thus they form a continuous contact system between bone cells, by which substances are transported from the central Haversian canal to the bone matrix, essential for the nutrition of bone cells. The Haversian or nutritient canals of the osteons communicate with the marrow cavity and the external surface via transverse channels, **Volkmann canals.** By means of this dense network of vessels, the bone becomes a heavily vascularised tissue. Changes in the mechanical forces acting upon bone cause a functional adaptation of the structure of the bone. Superfluous osteons are destroyed, their remaining fragments form **interstitial bone.** Toward the external surface of the bone, the lamellae form the outer cir-

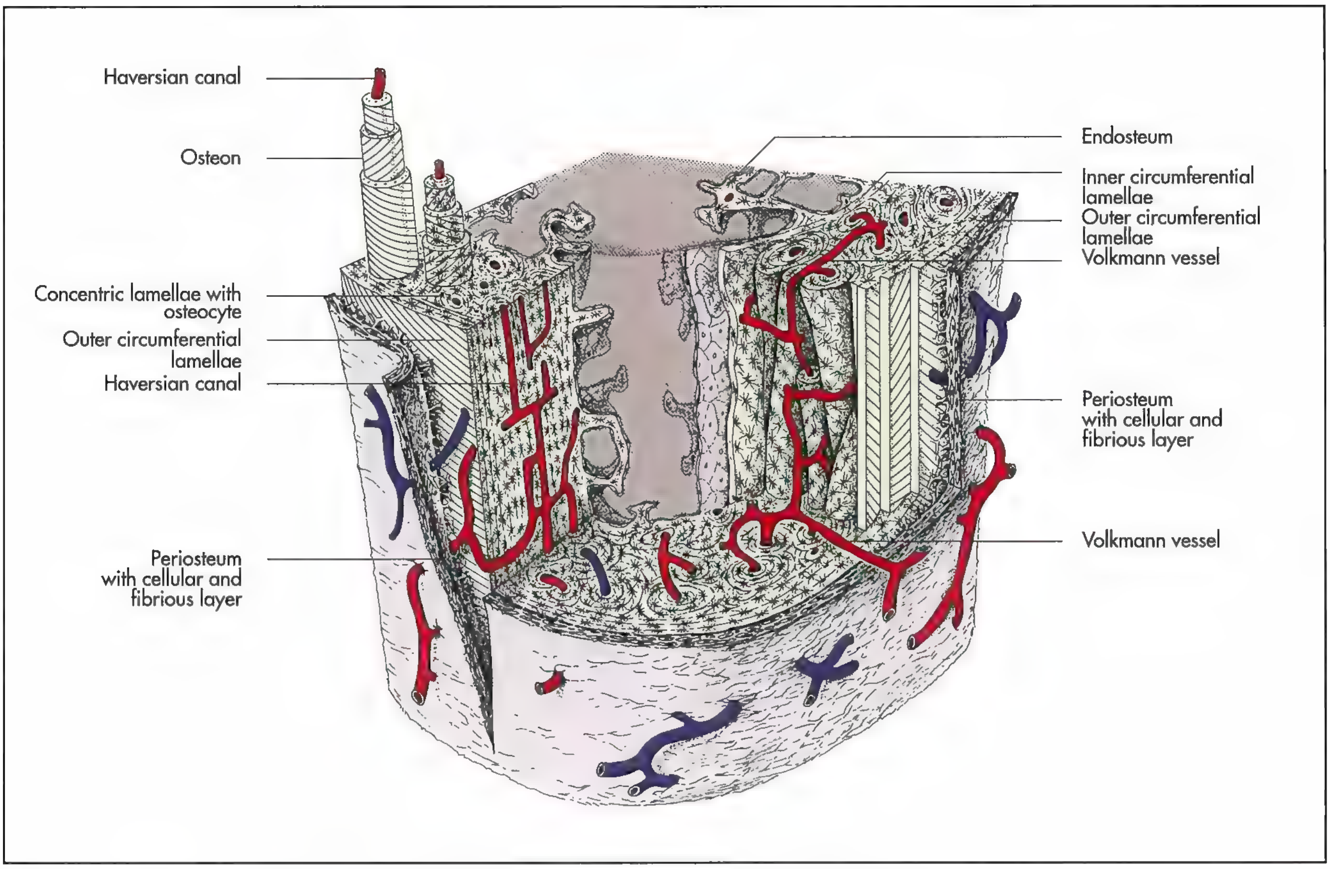

Fig. 0-11. Diagram of a section of compact bone from a diaphysis (schematic) (Liebich, 2004).

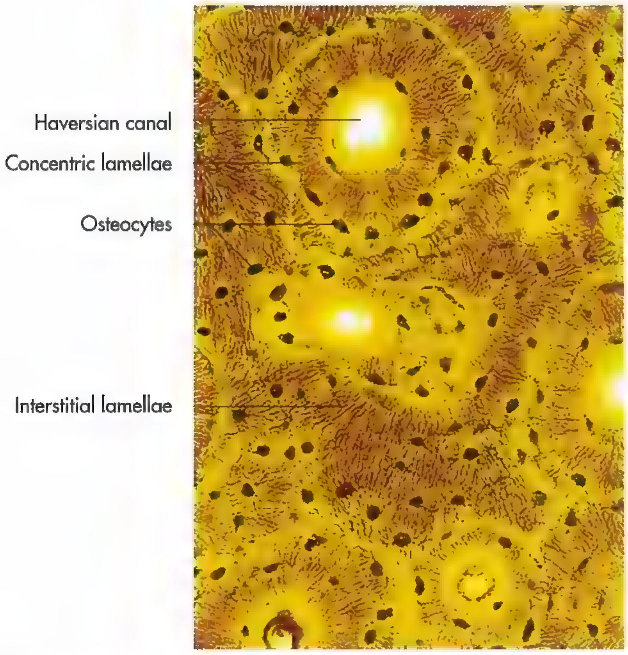

Fig. 0-12. Section of compact bone from a diaphysis (magnification 100 x, Schmorl staining).

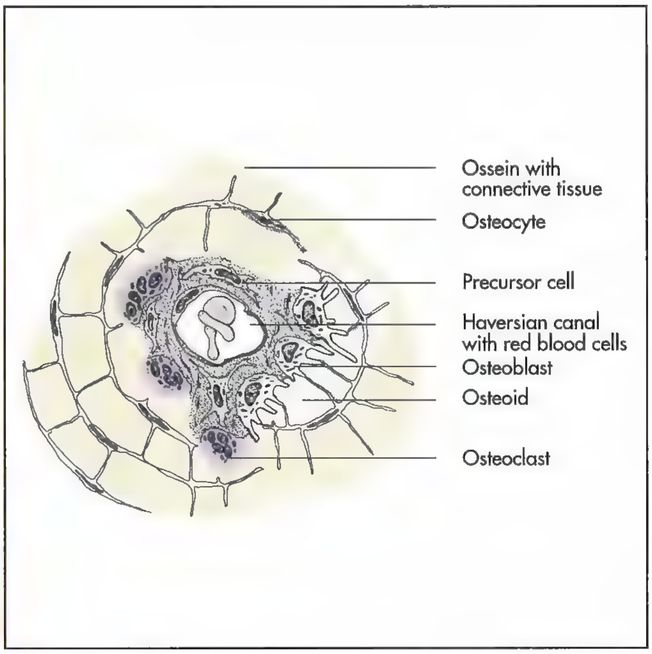

Fig. 0-13. Diagram of a cross-section of a developing osteon (schematic) (Liebich, 2004).

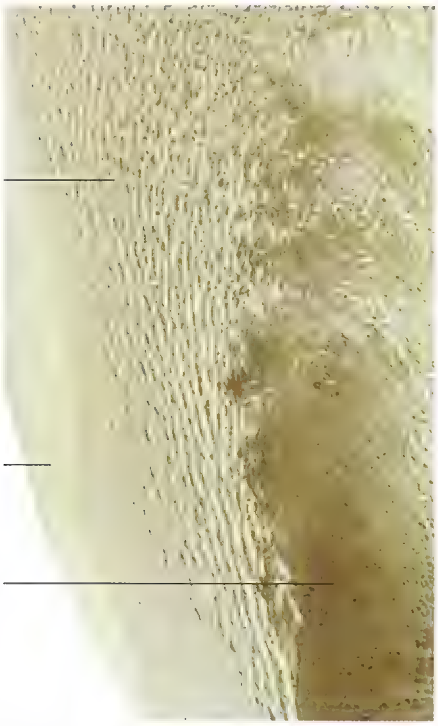

Fig. 0-14. Section of the wall of a long bone showing compact and trabecular bone.

Fig. 0-15. Section of lamellar bone.

cumferential layer, which surrounds the entire bone and is covered by the **periosteum.** A similar arrangement, the inner circumferential lamellae occurs toward the medullary cavity, which is lined by a thin fibrous membrane, the **endosteum.**

Firm adhesion between periosteum and bone is achieved by collagen fibres, which radiate into the external general lamellae (Sharpey fibres, fibrae perforantes). These collagenous fibres are formed by tendons of attachment and are essential for the transmission of the force from the muscle to the bone.

Classification of bones

Bones differ greatly in shape, size and strength among species, but also among individuals of the same species. This is caused by genetic determination of the development of bones, as well as static and dynamic influences in the growing and adult animal. Expansive attachment of muscle plates or punctual attachment of tendons on bones cause the development of processes, tubercles, crests, spines, roughened surfaces, depressions or notches. Blood vessels, nerves or organs are also able to contour the surface of bone (e.g. brain, eye, cochlea of the inner ear). Despite of the variety of bones, they can be classified by shape according to the following system:

Long bones (ossa longa) are characterised by a shaft or body (diaphysis) and a proximal and distal end (epiphysis proximalis et distalis). The form of the diaphysis is determined by a sheath or cortex of compact bone (substantia compacta), enclosing the central medullary cavity. Both extremities consists of cancellous or spongy bone, which forms a three-dimensional lattice of interlacing plates, tubes and spicules over which the cortex continues as a thin layer (Fig. 0-14 and 0-15). Long bones are typical in the limbs (Fig. 0-3).

Flat bones (ossa plana) consists of two layers of solid bone (tabulae) with spongy bone (diploe) or air-filled cavities (sinus) between them. This group includes the scapula and many bones of the skull. Some of the flat bones of the skull are pneumatised (ossa pneumatica).

Short bones (ossa brevia) vary greatly in shape, they can be cylindrical, cuboid or spheroid. They are occupied by a three-dimensional lattice of spongy bone with intervening haemoreticular tissue. The bones of the carpus, tarsus and of the spine are classified as short bones.

Sesamoid bones (ossa sesamoidea) develop in the capsules of some joints or in tendons (e.g. the patella or as part of the digital joints).

Some bones are not part of the locomotor apparatus and are located within organs, such as the bone in the penis of the dog or in the heart of the ox or the nose of the pig.

Figures 0-16 to 0-20 show the schematic skeleton of the domestic mammals as a whole to give an overall view of the topography of the bones. The individual bones are described in detail in later chapters.

Syndesmology (arthrologia)

The degree of mobility permitted between two adjacent bones largely depends on the type of articulation. Articulations **without a joint space** are termed **synarthroses.** These joints can either be filled with soft tissue, forming **fibrous junctions or joints** (junctura seu articulatio fibrosa) or with cartilage, forming **cartilaginous joints** (articulatio cartilaginea).

An increase in mobility between two bones is achieved by the formation of joint spaces (diarthrosis). **Synovial joints** (junctura seu articulationes synoviales) are characterised by a

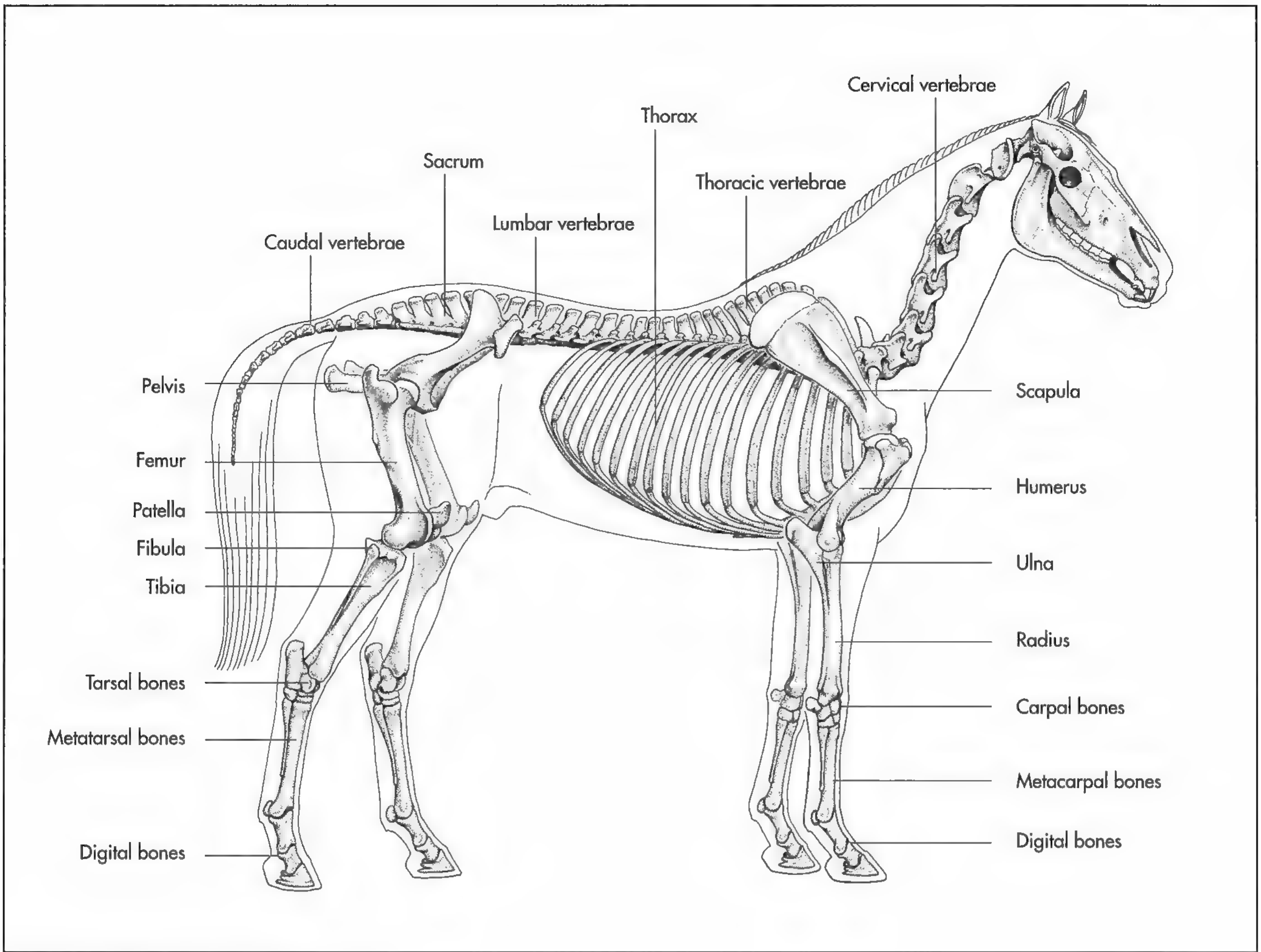

Fig. 0-16. Skeleton of the horse (schematic).

joint cavity (cavum articulare), filled with **joint fluid** (synovia).

Synarthroses

Fibrous joints (juncturae fibrosae) can be subdivided into:

- Syndesmoses, e.g. the attachment of the dewclaws to the metapodium in the ox,
- Sutures (suturae) unite the bones of the skull, There are different types of sutures:
- Serrate suture (sutura serrata),
  - Plane suture (sutura plana),
  - Squamous suture (sutura squamosa) and
  - Foliate suture (sutura foliata) and
- Gomphosis: e.g. the implanation of the teeth in the dental alveoli by the periodontal membrane.

Cartilaginous joints (juncturae cartilagineae) can be subdivided in:

- Hyaline cartilage joints (synchondroses): e.g. between the base of the skull and the hyoid bone,
- Fibrocartilaginous joints (symphyses): e.g. between the two halves of the pelvis or the mandible and
- Ossified junctions (synostoses): e.g. between the equine radius and ulna.

Synovial joints (articulationes synoviales)

Synovial, or true joints, vary with regards to the number of bones composing the joint, the amount and kind of mobility in them and the form of the joint surfaces. However, all joints have certain common structural and functional features (Fig. 0-25).

They share the following characteristics:

- Articular cartilage (cartilago articularis), usually hyaline, covers the articular surfaces of the bones,
- Joint cavity (cavum articulare) and
- Joint capsule (capsula articularis).

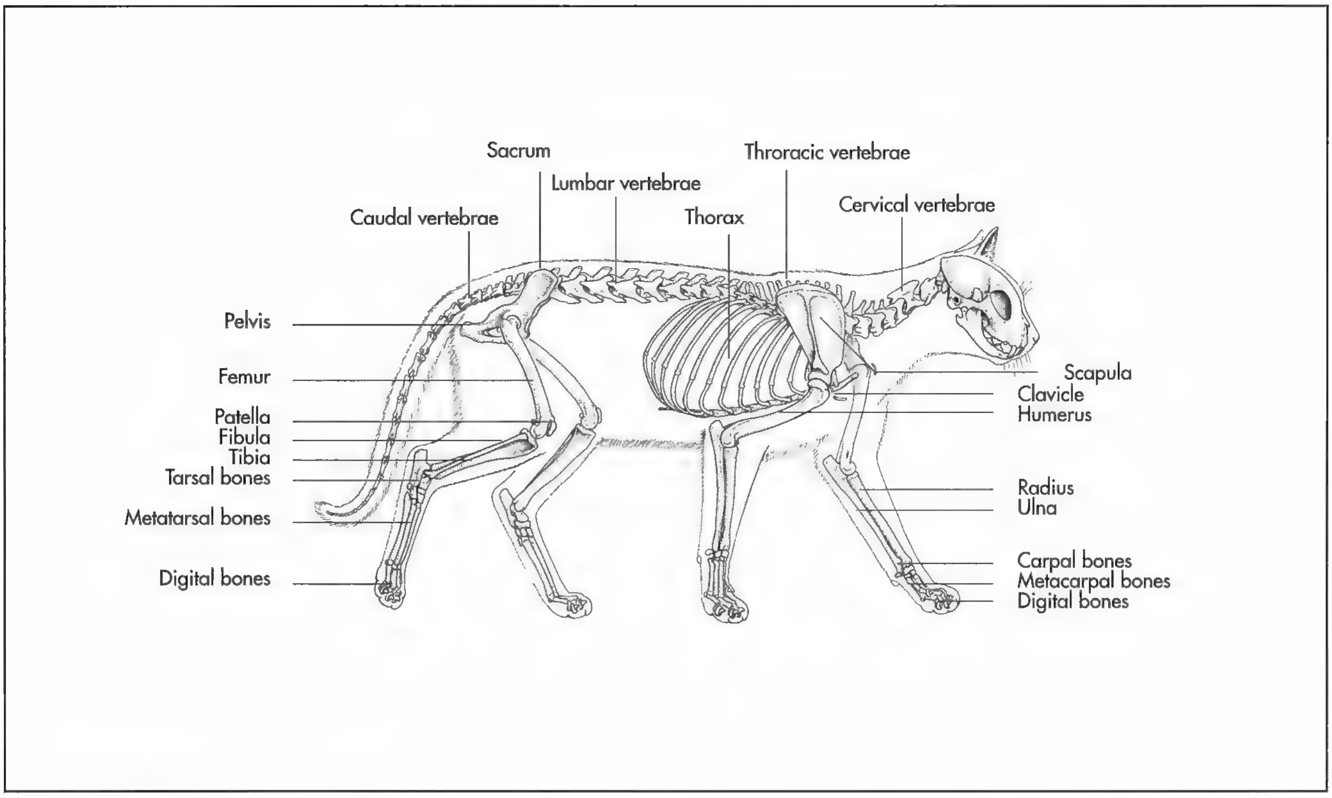

Fig. 0-17. Skeleton of the cat (schematic).

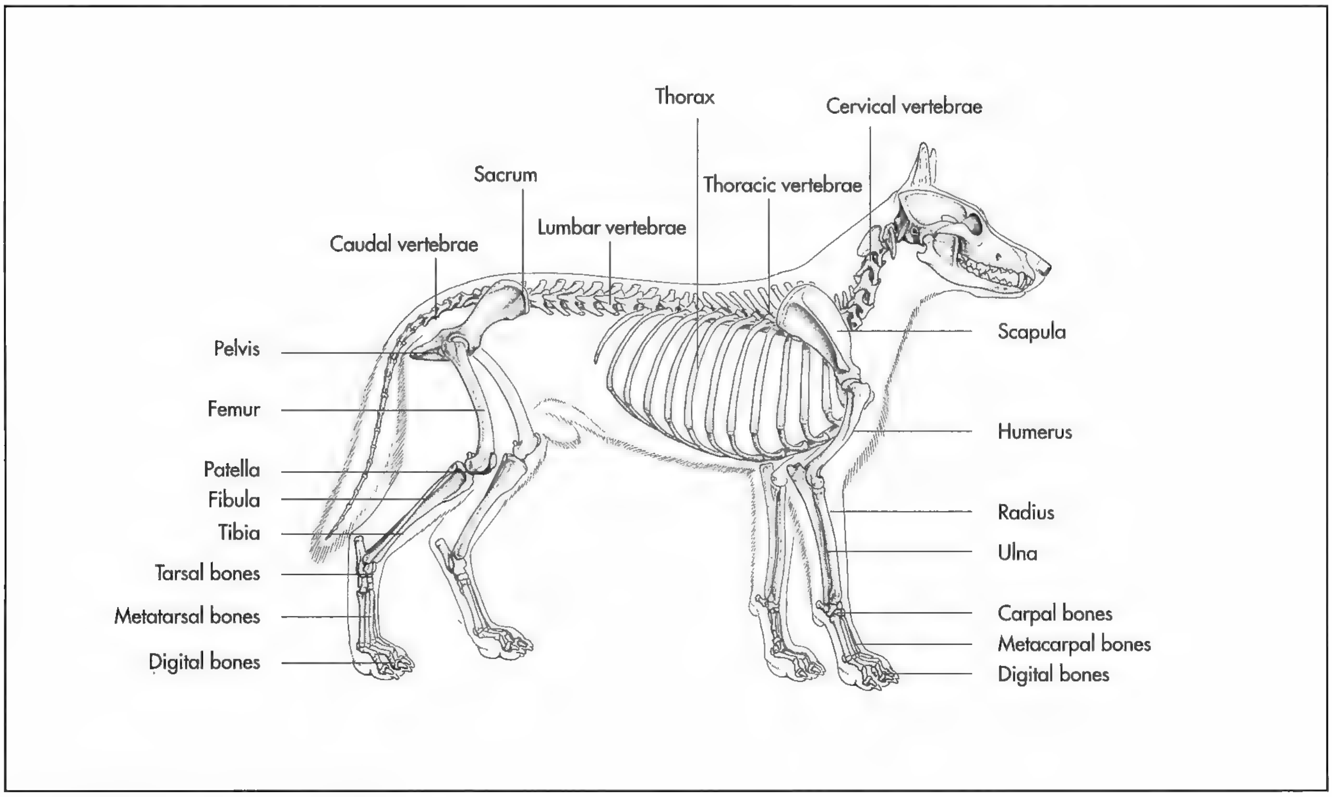

Fig. 0-18. Skeleton of the dog (schematic).

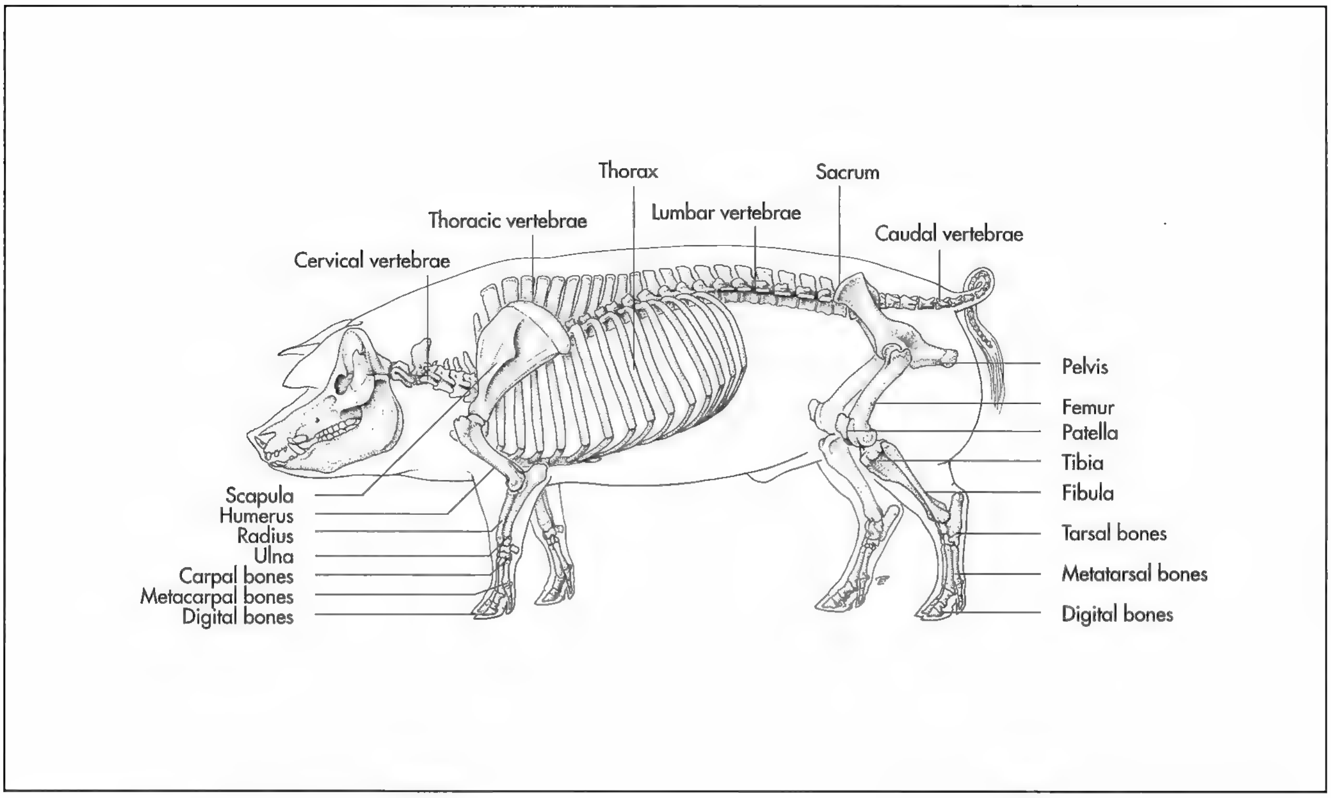

Fig. 0-19. Skeleton of the pig (schematic).

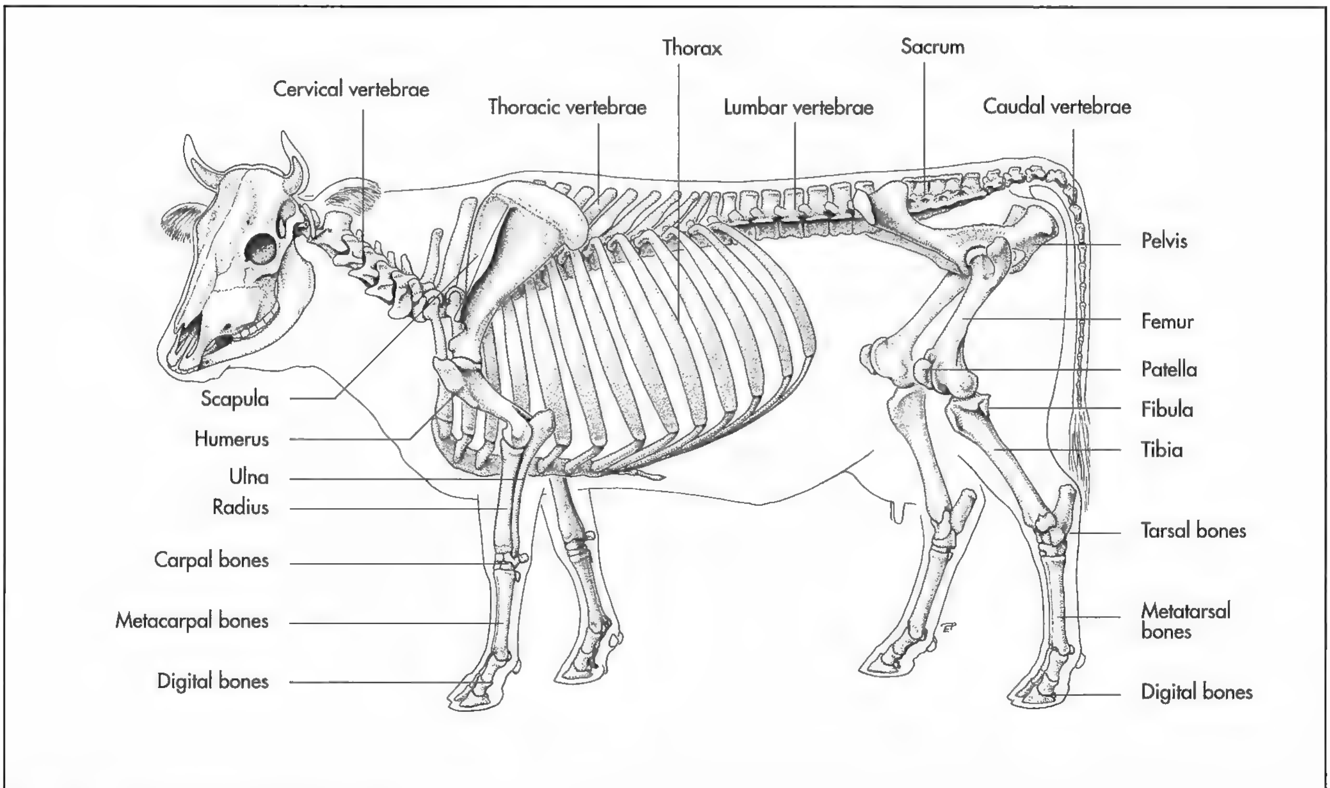

Fig. 0-20. Skeleton of the ox (schematic).

Fig. 0-21. Synovial villi free-floating within synovia (courtesy of Dr. Margit Teufel, Vienna).

Fig. 0-22. Synovial villi within the synovial cavity, capillaries injected (courtesy of Dr. F. Teufel, Vienna).

Fig. 0-23. An electron micrograph of synovial villi from the shoulder joint of a horse (courtesy of Dr. R. Böhmisch, Munich).

Fig. 0-24. An electron micrograph of synovial villi from the shoulder joint of a horse (courtesy of Dr. R. Böhmisch, Munich).

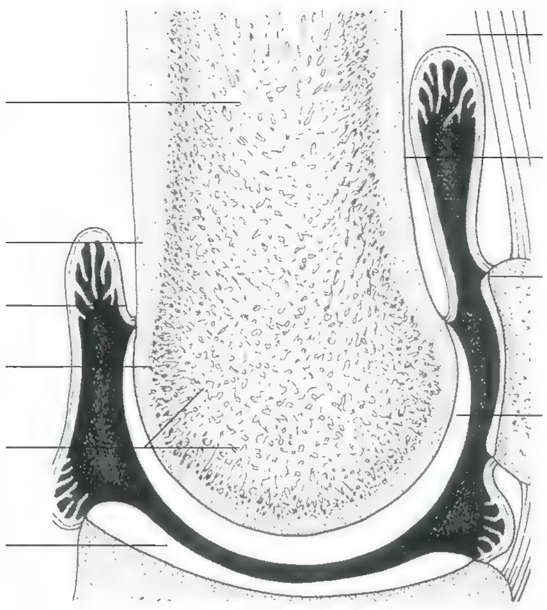

Fig. 0-25. Diagram of a synovial joint and adjacent sesamoid bone with suspensory apparatus (schematic).

Joints are held together by ligaments (ligamenta articularia), which can be extracapsular, intracapsular or be part of the joint capsule. Some joints include intra-articular plates of fibrocartilage between the articular surfaces. They form congruent articular surfaces, allow greater range of movement and diminish concussion. Examples are the **menisci in the stifle joint** (menisci articulares) or the **articular disc** (discus articularis) dividing the temporomandibular joint. Intraarticular fat pads are located in some joints for protection.

Articular cartilage forms a covering over the articular surface of the epiphyseal subchondral bone. The articular cartilage is not covered by perichondrium, but forms a smooth surface. The thickness of articular cartilage varies: on a concave surface the middle part is the thinnest, while on a convex surface the central part is the thickest. In ungulates the articular surface of several joints is interrupted by non-articular cavities known as synovial fossae (fossae synoviales). The collagen fibres of the matrix of the articular cartilage are orientated to withstand maximum stress and strain. Hyaline cartilage diminishes the effects of concussion and greatly reduces friction.

The **joint capsule** consists of two layers, the external layer is composed of **fibrous tissue** (stratum fibrosum), the internal layer is richly supplied by a network of blood vessels and nerves and is termed the **synovial layer or membrane** (stratum synoviale).

The fibrous layer of the joint capsule is continuous with the adjacent perichodrium or periosteum (Fig. 0-25). It can be strenghthened by ligaments, which are most commonly found on the outside of the joint. The thickness of the fibrous layer varies greatly in different joints, dependent largely on the mechanical forces it is subjected to. Injuries to the fibrous layer heal slowly due to the poor blood supply of this layer. The nerve supply is thought to be extensive, which results in considerable pain, when the joint capsule distends by an increase in the amount of synovial fluid.

The **synovial membrane** is white with a yellow tinge. The membrane has **folds** (plicae synoviales) and **villi** (villi synoviales), which project into the joint cavity and whose form, number and location differ within the joints. The synovial membrane can be further subdivided into a layer containing the **synoviocytes** (intima synovialis) and a **subsynovial layer** (stratum subsynoviale) (Fig. 0-21 to 0-25).

The inner layer of the synovial layer includes synoviocytes of two types. **Type A synoviocytes** are responsible for phagocytois, whereas **type B synoviocytes** produce proteins. The synovial membrane secrets a white-yellowish, viscous fluid, the **synovial fluid** (synovia), which can also be found in synovial bursae and tendon sheaths. It lubricates the joint to reduce friction between the articular surfaces. It also serves to transport nutrient material to the hyaline articular cartilage, and as such contains carbohydrates, electrolytes, enzymes and hyaluronic acid. "Joint mice" are intraarticular pieces of cartilage or bone, which result from a chip-fracture or ossification of synovial pads. Depending on their location they can be very painful.

The joint cartilage lies directly on a thin subchondral bone layer above the epiphysis. It is not covered by perichondrium, but has a smooth surface towards the joint cavity (Fig. 0-25 and 26). The joint cartilage is thinner in the centre of the concave areas and thicker in the convex parts of the joint. In hooved animals various joints show a reduction of cartilage in the border zones, forming synovial fossae. The orientation of the bundles of collagen fibres in the matrix of the cartilage

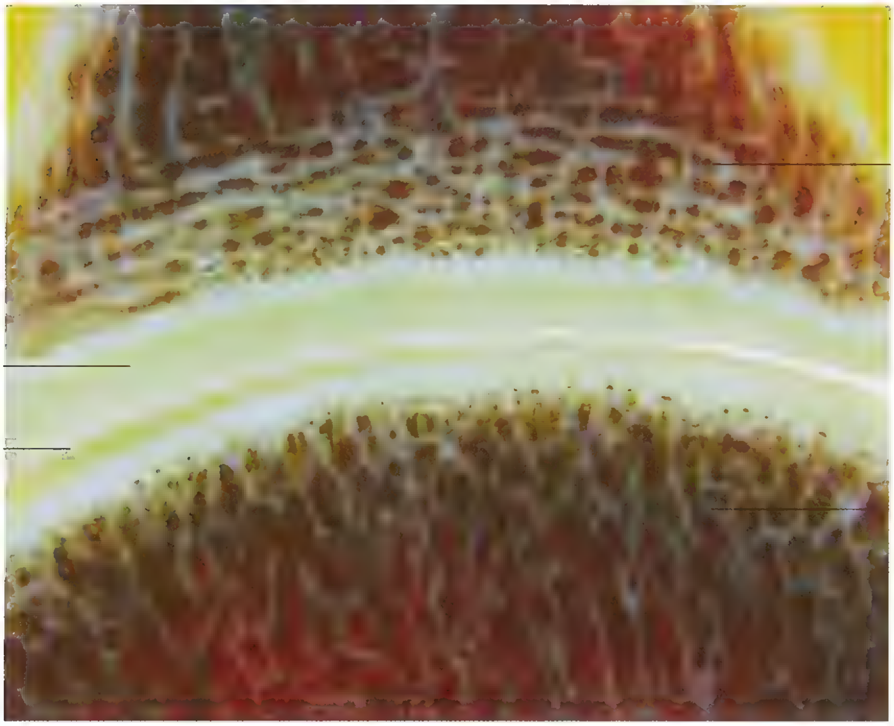

Fig. 0-26. Section of the shoulder joint of a dog bordered by the bone ends (plastination).

is strictly based on the mechanical laws of tensile stress. The network of the hyaline cartilage works as a shock-absorber and posesses flexible and viscoelastic properties. The cartilage lacks nerves and contains virtually no blood vessels.

The articular cartilage can be divided into different zones:

- Superficial zone,
- Intermediate zone,
- Radiate zone and
- Calcified zone.

The superficial zone consists of tight meshwork of horizontal collagen fibres. These fibres curve in direction of the joint surface, where they finally show a parallel orientation. This structure of the collagen fibres increases the stability of the joint cartilage towards the surface.

The intermediate zone is strucurally homogeneous. The radiate zone includes fibres that are arranged radially. In the calcified zone the bundels of collagen fibres are linked to a calcified layer above the bone. Hereby a thight connection between the cartilage and the bone is ensured.

Below the joint cartilage lies the subchondral bone plate that consists of the calcified layer of the cartilage and lamellar layers of bone. This plate supports the dynamic functions of the joint, protects the cartilage against axial stresses like a mechanical shock-absorber and upholds the metabolism of the deeper layers of the cartilage.

The joint cartilage has an anaerob metabolism. It is sustained bradytrop through diffusion and rarely via the synovial fluid in the gaps of the joint cavity or medullar vessels. The high content of proteoglycans and their increased abillity to bind water, facilitates the intrachondral transport of metabolites.

Joints are held in place by intracapsular, capsular or extracapsular joint ligaments (ligamenta articularia). A few joints also contain fibrocartilagous meniscus (mensici articulares) in the knee joint or discs (disci arrticulares) in the mandibular joint, in order to compensate the incongruency of the joint surfaces and stabilize the joint. Furthermore intraarticular adipose tissue can function of a buffer.

Synovial joints can be classified according to the following criteria:

1. Number of bones forming the joint
- **Simple joints** (articulatio simplex) with one pair of articular surfaces, e.g. the shoulder joint,
- **Composite joints** (articulatio composita) in which more than two surfaces are involved, e.g. the carpus.

2. Degree and kind of mobility
- **Uniaxial joints:**
  - **Hinge joint** (ginglymus): the joint axis is perpendicular to the long axis of the bone, e.g. elbow joint,
  - **Pivot joint** (articulatio trochoidea): the joint axis is parallel to the long axis of the bones, e.g. atlantoaxial joint,
- **Biaxial joints:**
  - Saddle joint (articulatio sellaris), e.g. interphalangeal joints,
  - Ellipsoidal joint (articulatio ellipsoidea), e.g. atlantooccipital joint

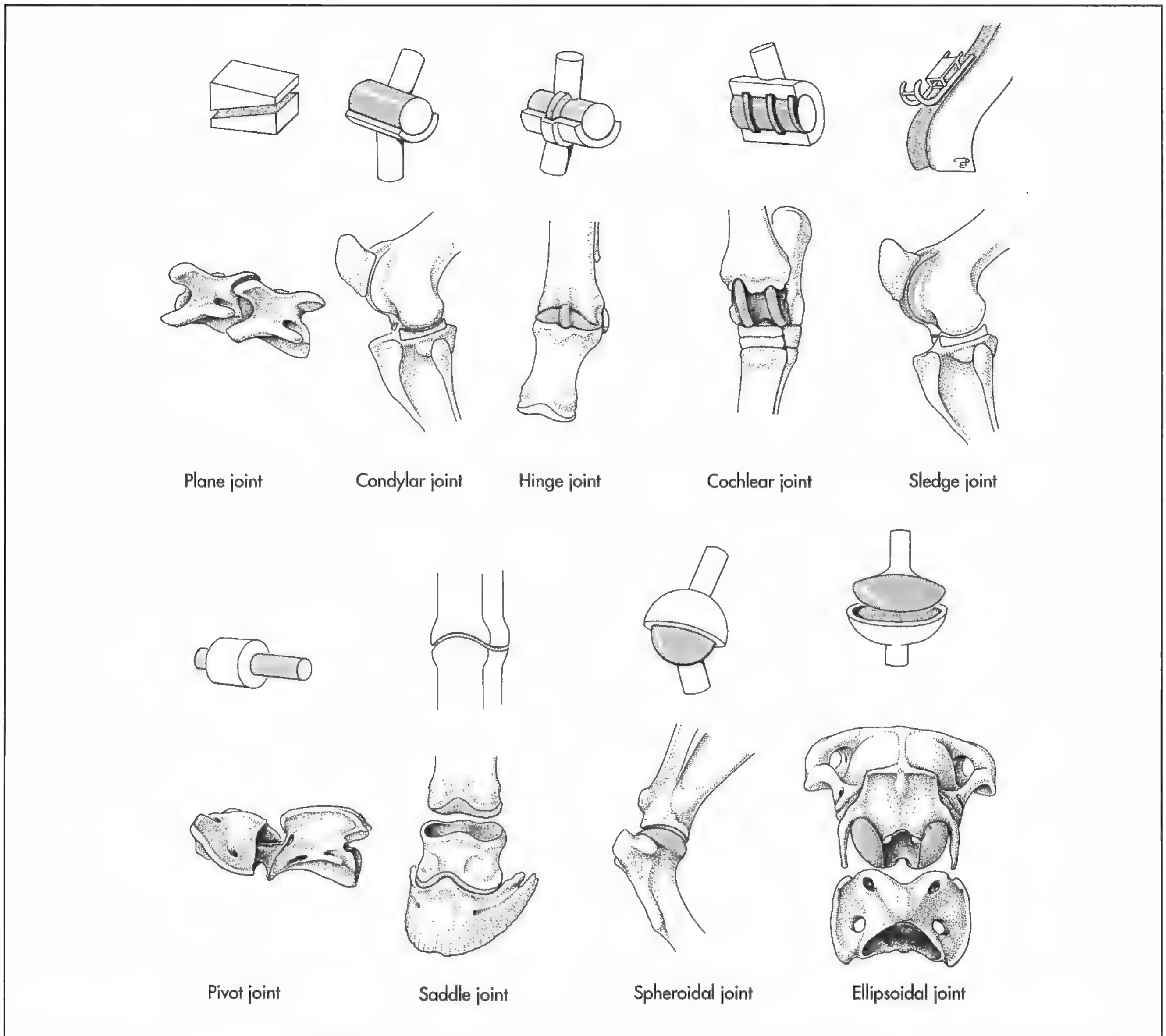

Fig. 0-27. Types of synovial joints (schematic).

- **Multiaxial joints,** e.g. shoulder and hip joint,
- **Tight joints** (amphiarthrosis), e.g. sacroiliac joint.

3. Form of the articular surfaces
- **Spheroidal or ball-and-socket joint** (articulatio spheroidea), e.g. shoulder and hip joint,
- **Cotyloid joint** (articulatio cotylica): Spheroidal joint, where the convex articular surface is enclosed in the articular cavity beyond its equator, e.g. the human hip joint,
- **Ellipsoidal joint** (articulatio ellipsoidea), e.g. atlantooccipital joint,
- **Saddle joint** (articulatio sellaris), e.g. interphalangeal joints,
- **Condylar joint** (articulatio condylaris).

The last group comprises the following subdivisions, characterised by special functional features:

- **Hinge joint** (ginglymus), e.g. elbow joint,
- Cochlear joint (articulatio cochlearis), e.g. tarsocrural joint of the horse,
- **Spring or snap joints:** the strong collateral ligaments are attached eccentrically, proximal to the joint axis, e.g. the elbow and tarsal joints of the horse,
- **Sledge joint** (articulatio delabens), e.g. the femoropatellar joint,
- **Spiral joint** (articulatio spiralis): the strong collateral ligaments are attached eccentrically, distal to the joint axis. They are shorter in the "neutral" position of the joint, but get tensed during flexion or extension, thus exerting a brake-like effect, e.g. the stifle joint of the horse,

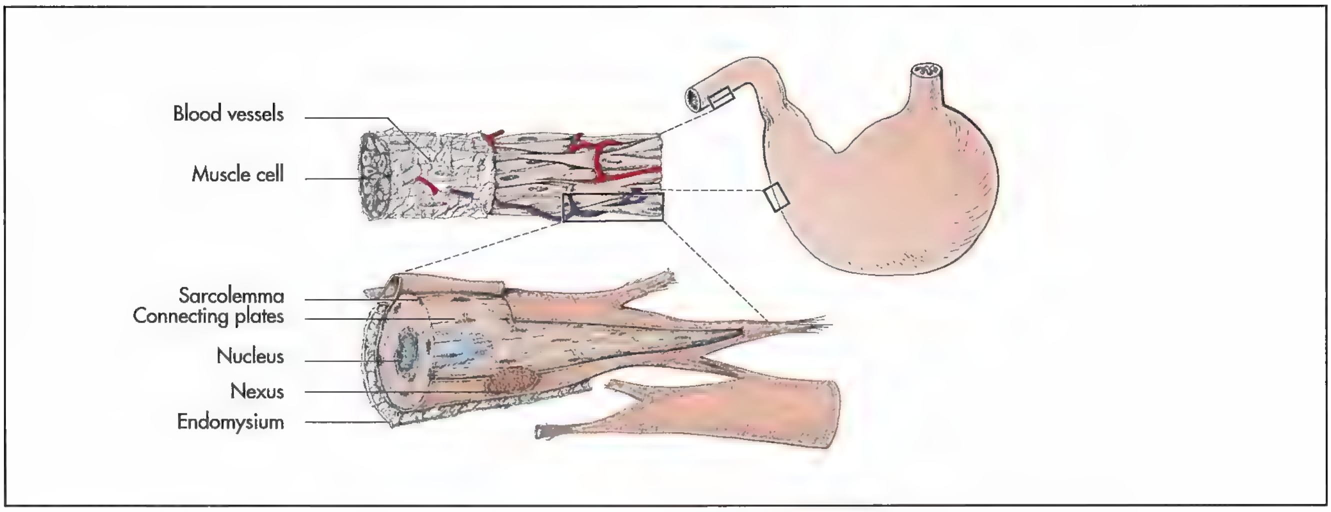

Fig. 0-28. Architecture of smooth muscle (schematic) (Liebich, 2004).

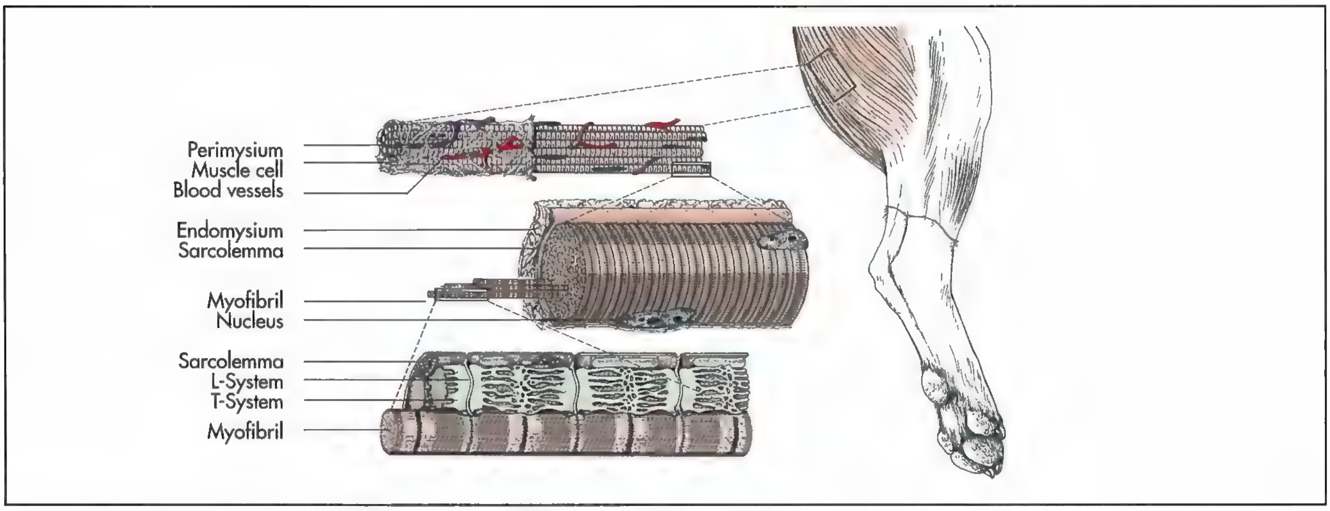

Fig. 0-29. Architecture of striated muscle (schematic) (Liebich, 2004).

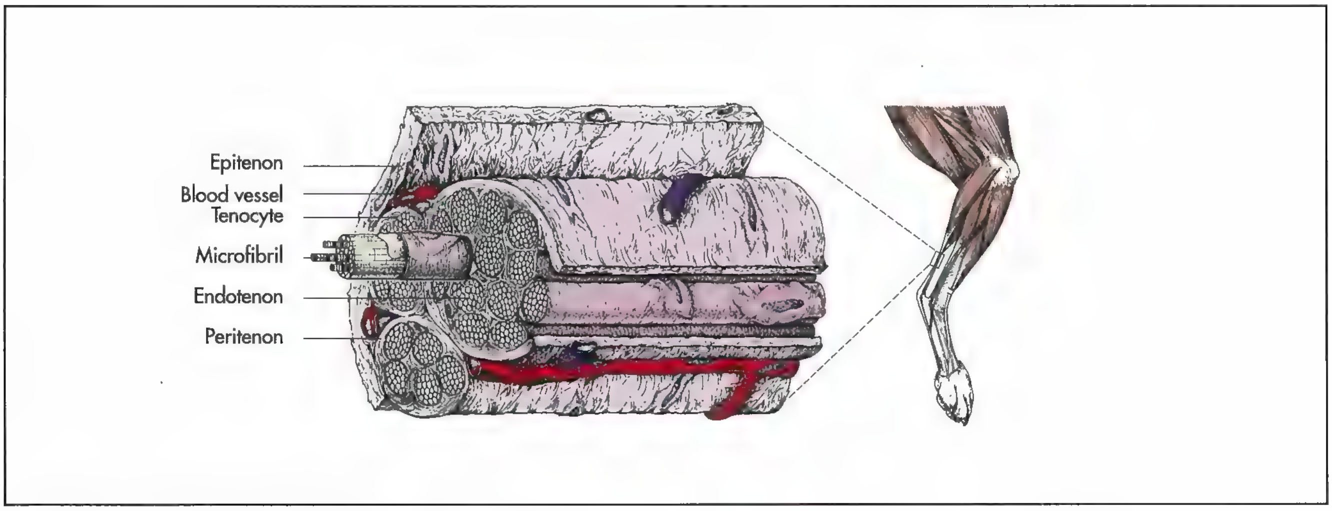

Fig. 0-30. Architecture of tendon (schematic) (Liebich, 2004).

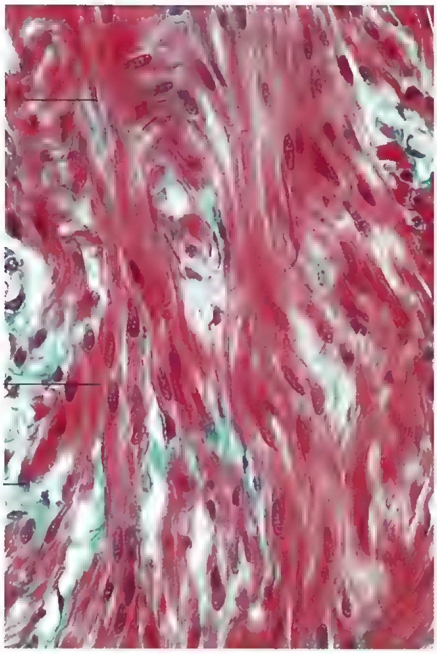

Fig. 0-31. Longitudinal section of a smooth muscle (magnification 400 x, Goldner staining).

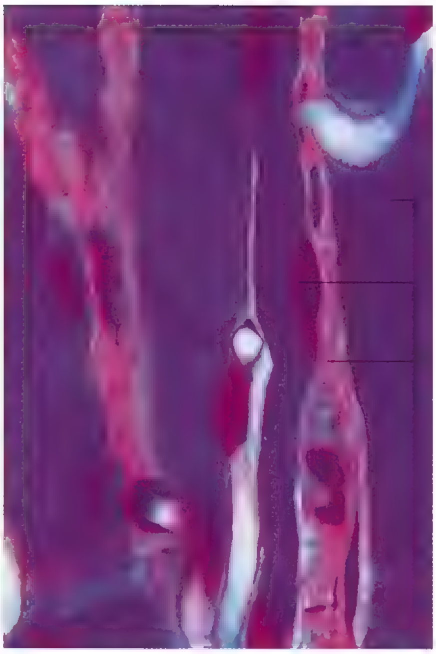

Fig. 0-32. Longitudinal section of a skeletal muscle (magnification 800 x, methylene blue and safranine staining).

- **Plane joints** (articulatio plana), e.g. the joints between the articular processes of the vertebrae,
- **Incongruent joints:** the form of the articular surfaces do not correspond, e.g. the femorotibial joint or the temporomandibular joint. In these joints fibroarticular menisci or discs render the surfaces congruent.

Muscular system (systema musculare)

Myology (myologia)

In higher organisms the **mesodermal cells** have the ability to specialise into somites and their derivatives, which possess the property of contractility. This cell population develops into muscular tissue, which is able to transform chemical energy into mechanical energy or heat.

Muscle tissue is classified both functionally and morphologically into **two major categories** (Fig. 0-28, 29, 31 and 32):

- **Smooth muscle,** which occurs in the walls of hollow organs, blood vessels and glandular ducts,
- **Striated muscle,** which includes **skeletal muscle** and **cardiac muscle.**

Skeletal musculature constitutes the active part of the locomotor system. In general the term "muscle" or "musculature" is only applied to this category. Skeletal muscles are well-supplied by blood vessels and nerves, with which they form functional units. Expansive soft tissue sheets, such as fasciae or aponeuroses, as well as synovial structures, such as tendon sheaths or bursae support and protect the muscles.

By always attaching to bone or cartilage, skeletal musculature provide forces for locomotion and posture of individual parts of the body or the body as a whole (see also chapter 5 "Statics and Dynamics"). It also plays an important role in supporting the body weight, forming the thoracic and abdominal walls and acting upon the function of the internal organs (e.g. respiratory muscles, diaphragm).

Development, degeneration, regeneration and adaptation of muscle fibres

The pre-natal development of muscle cells starts with the differentation of **mesenchymal stem cells** of the mesodermal somites into **premyoblasts** and then to **contractile myo-blasts.** These cells include **myofilaments** and **actinfilaments,** which contain the proteins myosin and actin respectively. They appear **striated** due to the arrangement of these contractile proteins. Long, cylindrical, multinucleated muscle cells, also called muscle fibres, are formed by the fusion of adjacent myoblasts. In the adult, these muscle cells can be over 10 cm in length and more than 100 μm in diameter.

Some stem cells remain in their original stage and form so-called **satellite cells,** which play an important role in the regeneration of damaged muscle tissue. Various factors (local ischemia, neural atrophy, pressure damage) can cause a local degeneration of the muscle, the regeneration of which is largely dependant on the number and activity of the undamaged satellite cells.

The **thickness of a muscle** is influenced by the degree of exercise the muscle is subjected to. Continuous exercise

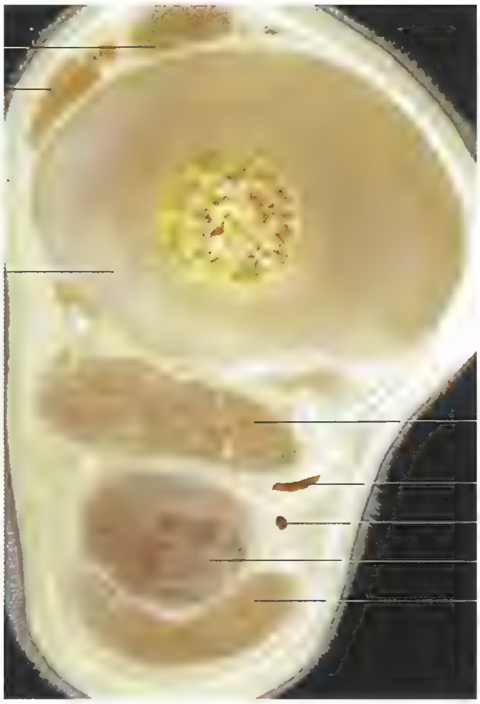

Fig. 0-33. Transversal section of the metacarpus in a horse, middle third (plastinated preparation).

leads to hyperplasia of the muscle mass by thickening of the muscle fibres, strengthening of the soft tissue components and an increase in blood supply, whereas interruption of the nerve supply or lack of exercise leads to muscle atrophy.

Organisation of muscles

Skeletal muscles consist of a muscle belly which can contract. The **tendons of origin** and **insertion** attach to each end of the **muscle belly** and transmit the force, generated by the belly, onto the passive part of the locomotor system (Fig. 0-29). Microscopically the muscle cells appear striated because of the parallel and regular arrangement of the actin and myosin filaments within each muscle fibre (0- 29).

Muscle cells differ in the number of contractile myofilaments in their sarcoplasm. If fibres contain a high number of myofilaments, they can only store a limited amount of myoglobin, thus appear to be **"white".** These type of muscle fibres are of high contractility with short duration. **"Red"** muscle fibres have less myofilaments, but contain more myoglobin, thus they can contract over relatively prolonged periods, but with little force. Further details on muscle contraction can be found in standard physiology and histology textbooks.

Muscles are innervated by branches of the cerebrospinal nerves, half of the fibres being motor and the other half sensory. Each motor axon supplies several muscle fibres. These **neuromuscular units** are known as motor units. **Efferent nerve fibres** form motor end-plates, which are neuromuscular junctions on muscle fibres with acetylcholine as the neurotransmitter. **Sensory nerve fibres** end in encapsulated groups of muscle spindles. These **muscle spindles** act as receptors and provide information about muscle tone and the degree of tension of tendons or joint capsules. They also contribute to the coordination of locomotion and the position of body parts in relation to each other. Tendon organs are similar to muscle spindles and function as receptors for the tension within the muscle-tendon unit. Intramuscular blood and lymphatic vessels are innervated by parasympathetic or sympathetic branches of the autonomic nervous system to ensure adequate blood flow and lymphatic drainage.

The surface of the entire muscle is covered by a dense network of reticular fibres, the **epimysium,** which continues onto the tendon as **epitenon.** This soft tissue sheath is visible with the naked eye and separates adjacent muscles from each other, reduces friction between them and transmits nerves, blood and lymphatic vessels. The definite muscle is composed of fibres grouped into bundles surrounded by soft tissue, the **perimysium** (Fig. 0-29). Each muscle fibre is surrounded by a network of delicate collagen fibrils, the **endomysium.** This forms a sheath, which also includes soft tissue cells, small blood vessels and nerves (Fig. 0-29). These soft tissue sheaths can be classified by the size of the bundles they enclose, into primary, secondary and tertiary bundles. They merge at each end of the muscle belly and continue as the tendon by which the muscle attaches. They provide an efficient transmission of the force, generated by the muscle belly onto the tendon. The **musculo-tendinous junction** is formed by a multitude of digitations between the muscle fibres and the tendon fibrils.

Tendons are white cords, composed of collagen bundles of different diameter and length in parallel arrangement. These bundles are the direct continuations of the soft tissue components of the muscle and show the same subdivision into primary, secondary and tertiary bundles as the muscle

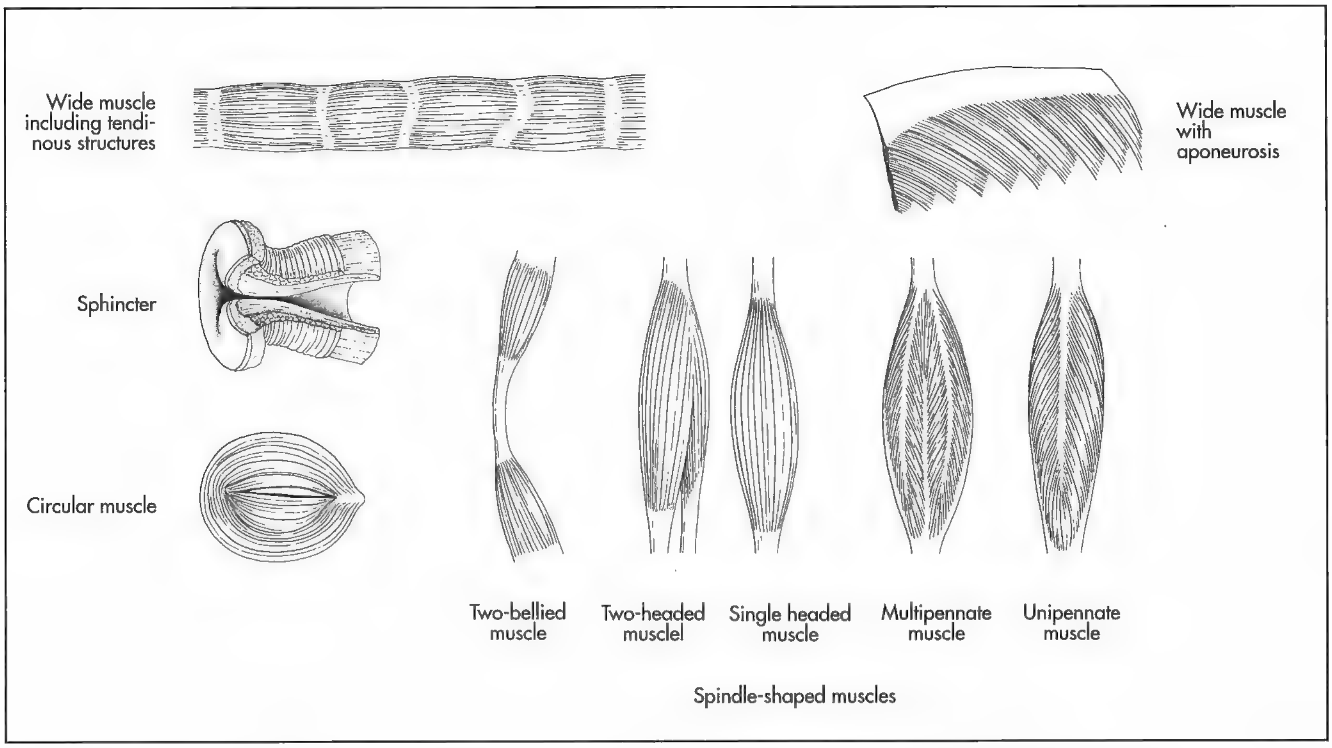

Fig. 0-34. Categories of skeletal muscles according to the arrangement of their fibers (schematic) (Putz and Pabst, 1993).

(Fig. 0-30). Expansive muscle plates form flat, sheet-like aponeurosis as means of attachment. The fibres of both, tendons and aponeuroses, are orientated in the direction of the mechanical load they are subjected to. Tendons are almost entirely composed of **collagen bundles** with some **elastic fibres** and **matrix proteins,** thus they possess great tensile strength which by far exceeds the strength of muscular tissue.

At the site of attachment of the tendon to bone or cartilage the tendon fibres radiate into the periosteum or the perichondrium and continue as so called **Sharpey-fibres** within the bone. The area of attachment can be short or expanded over a larger area. Some tendons end by radiating into soft tissue, such as the tongue or the skin. These tendons are characterised by a high content of elastic fibres. Most tendons broaden out and split into several sheets at their junction with their muscle.

Muscles in which the muscle fibres join the tendon in an angle, can be grouped in several categories based on the orientation of the fibres (Fig. 0-34):

- **Unipennate muscle** (m. unipennatus) with two parallel tendon sheets,
- **Bipennate muscle** (m. bipennatus) two tendon sheets of different direction,
- **Multipennate muscle** (m. multipennatus) several tendon sheets of different directions.

By increasing the number of divisions, the number of muscle fibres can be increased without enlarging the thickness of the muscle, resulting in an increase in **muscular strength.** The force a muscle may develop is a function of the aggregate of its functional cross-sectional area: the more fibres contained within this area the greater the **power of the muscle.** In order to calculate this force, it is necessary to substitute for the simple **anatomical cross-section** the "physiological" cross-section, the complex plane that divides the muscle in such a way, that each fibre is cut across its axis.

The work of a muscle is a function of force and the shortening a muscle may demonstrate on contraction. The shortening depends on the length of the muscle fibres and the way the angle of attachment changes with contraction. The power of a muscle designates the speed of contraction.

The muscle fibres of strong muscles tend to join the tendons or attach to bones at an acute angle to have more space available for the contracted muscle and to increase their potential of displacement. This anatomical arrangement improves blood supply and promotes muscle metabolism. Muscular action plays an important role as active regulation mechanism for the whole circulatory system.

Classification of muscles

Muscles differ widely in shape, size and location. A spindle-shaped muscle is composed of the passive **head** (caput) at its origin, the active **belly** (venter) in the middle and the passive **tail** (cauda) at its end. The attachments of the muscle, which remain stationary during movement are termed the origin and insertion. Most commonly, the **origin** denotes the more proximal or central attachment while the **insertion** the more distal or peripheral attachment. Muscles can be grouped into the following categories according to their shape (Fig. 0-34):

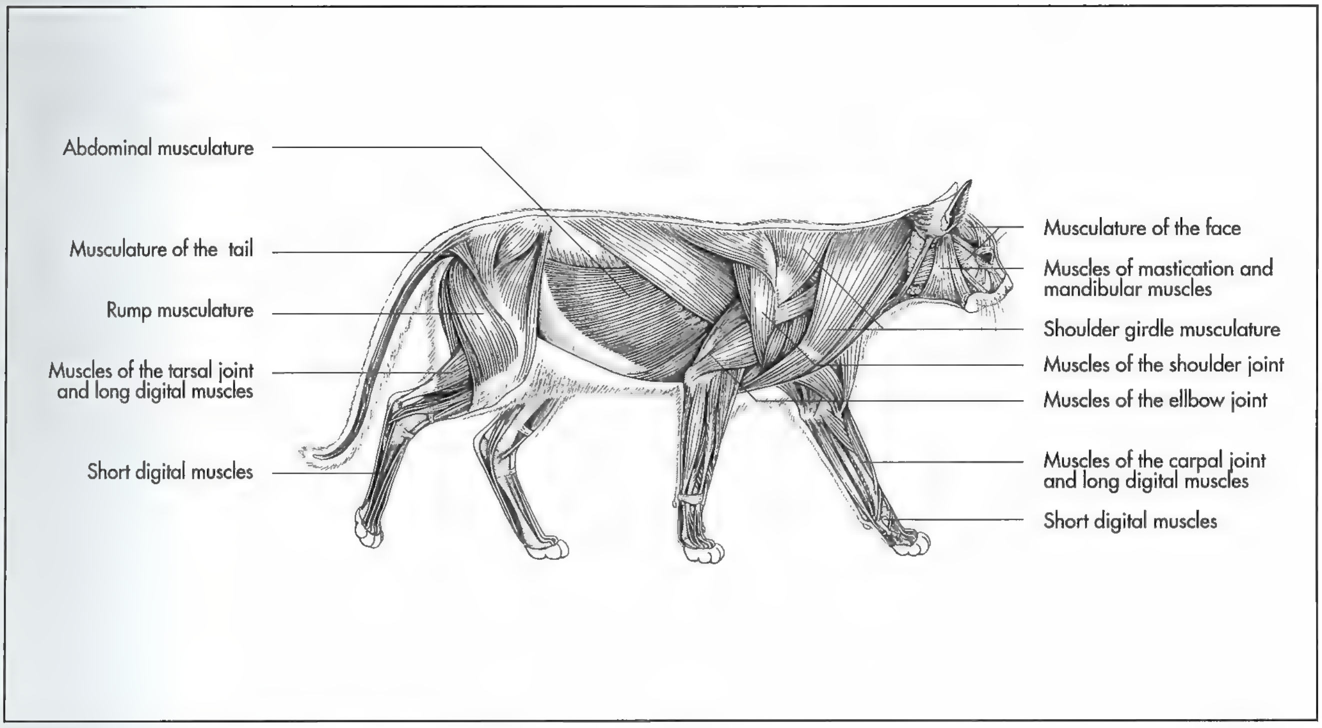

Fig. 0-35. Superficial musculature of the cat (schematic).

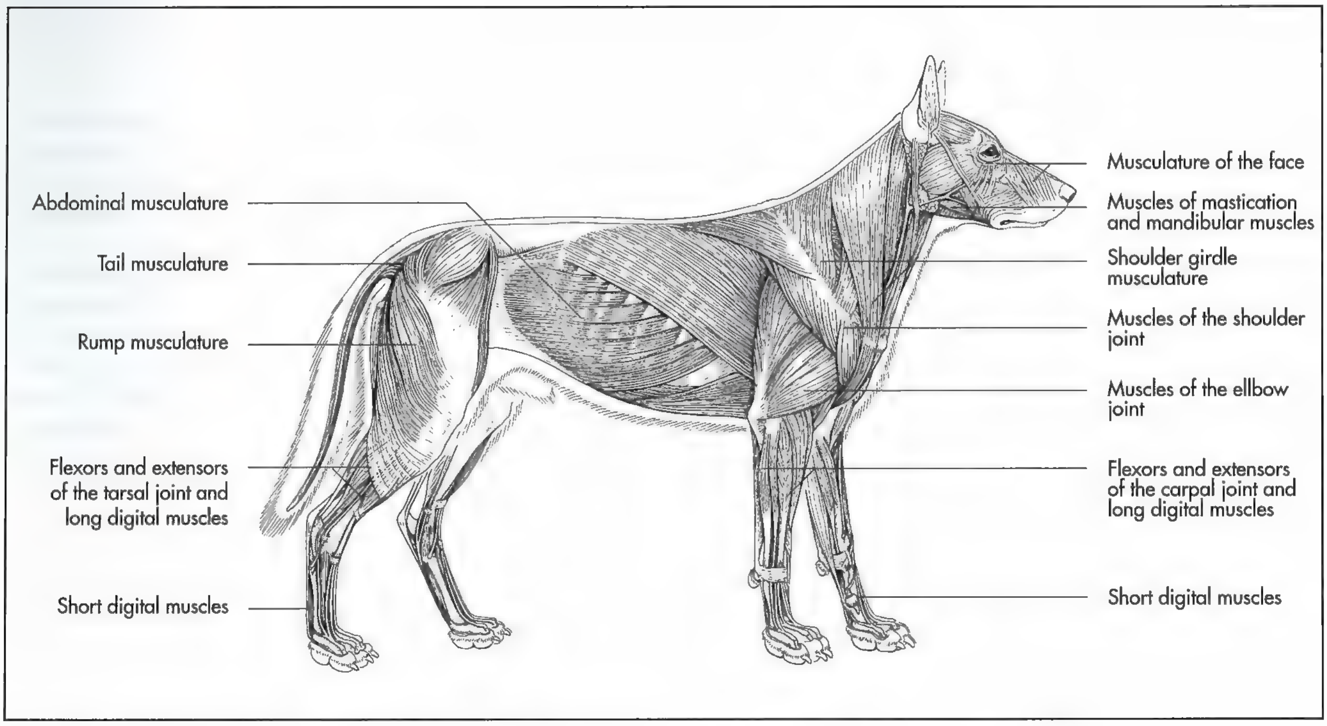

Fig. 0-36. Superficial musculature of the dog (schematic).

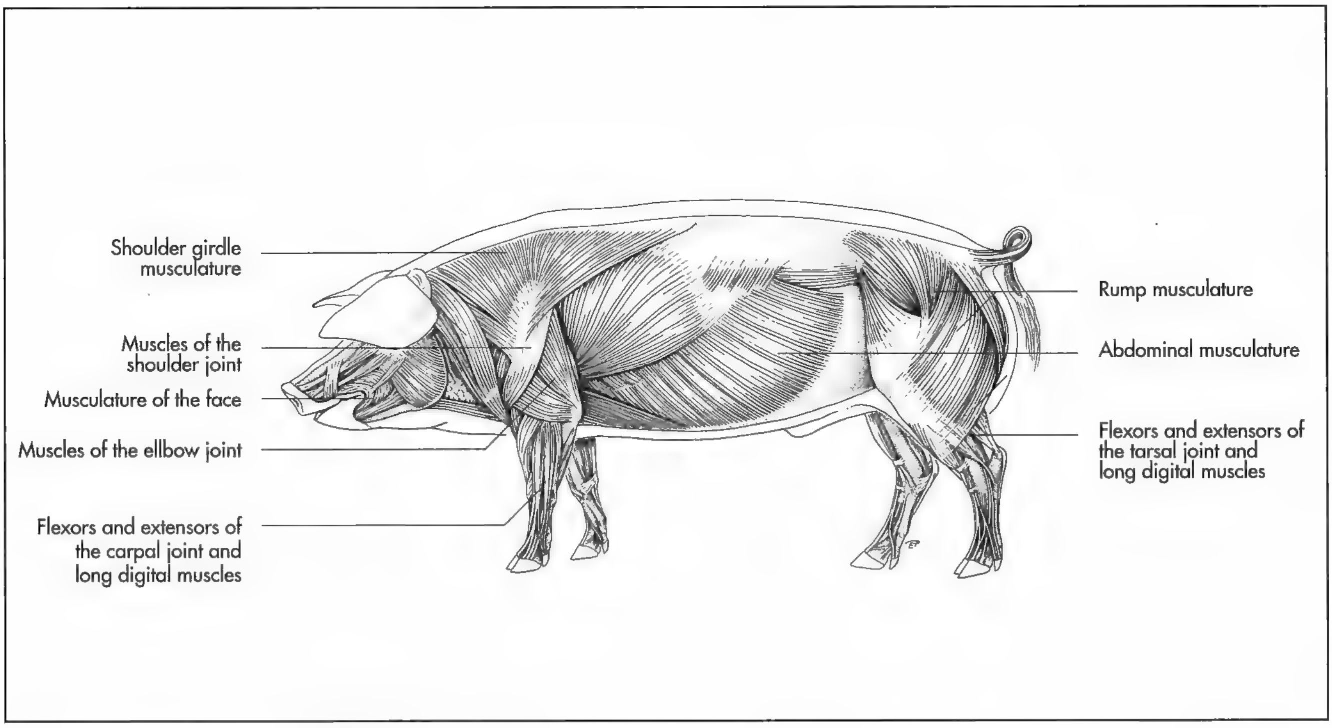

Fig. 0-37. Superficial musculature of the pig (schematic).

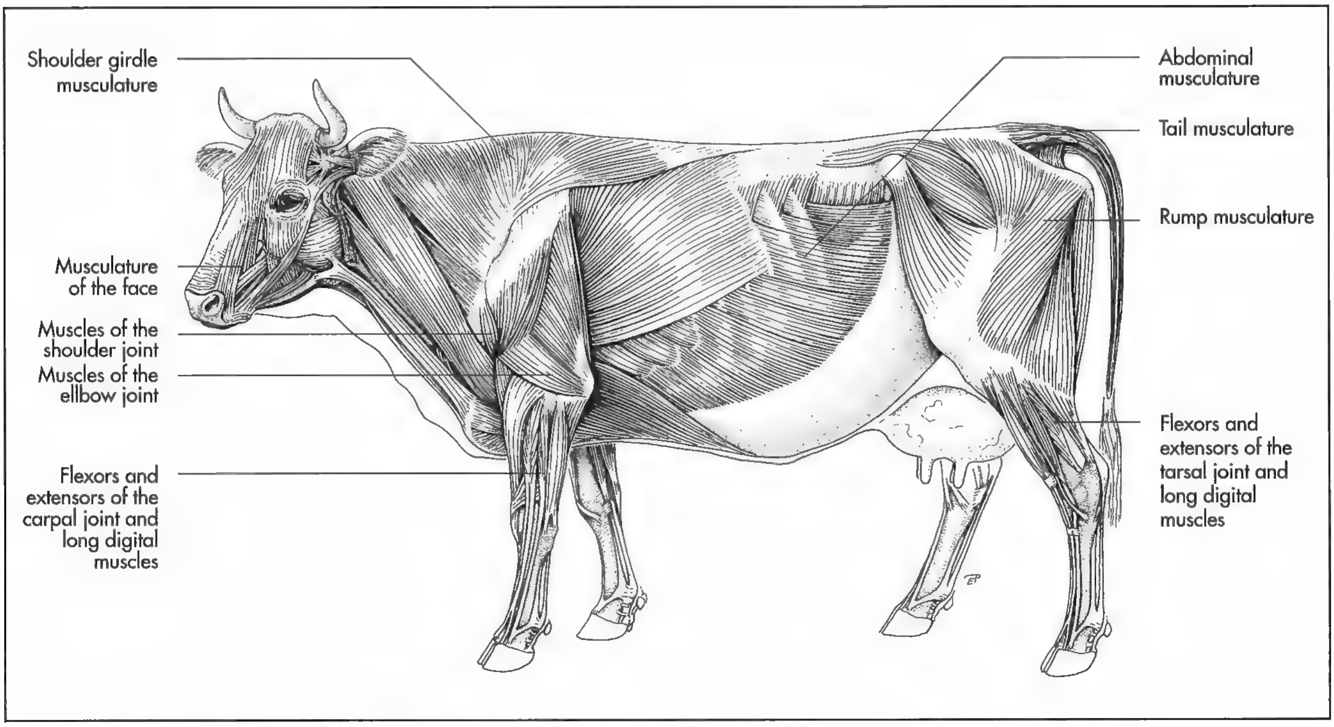

Fig. 0-38. Superficial musculature of the ox (schematic).

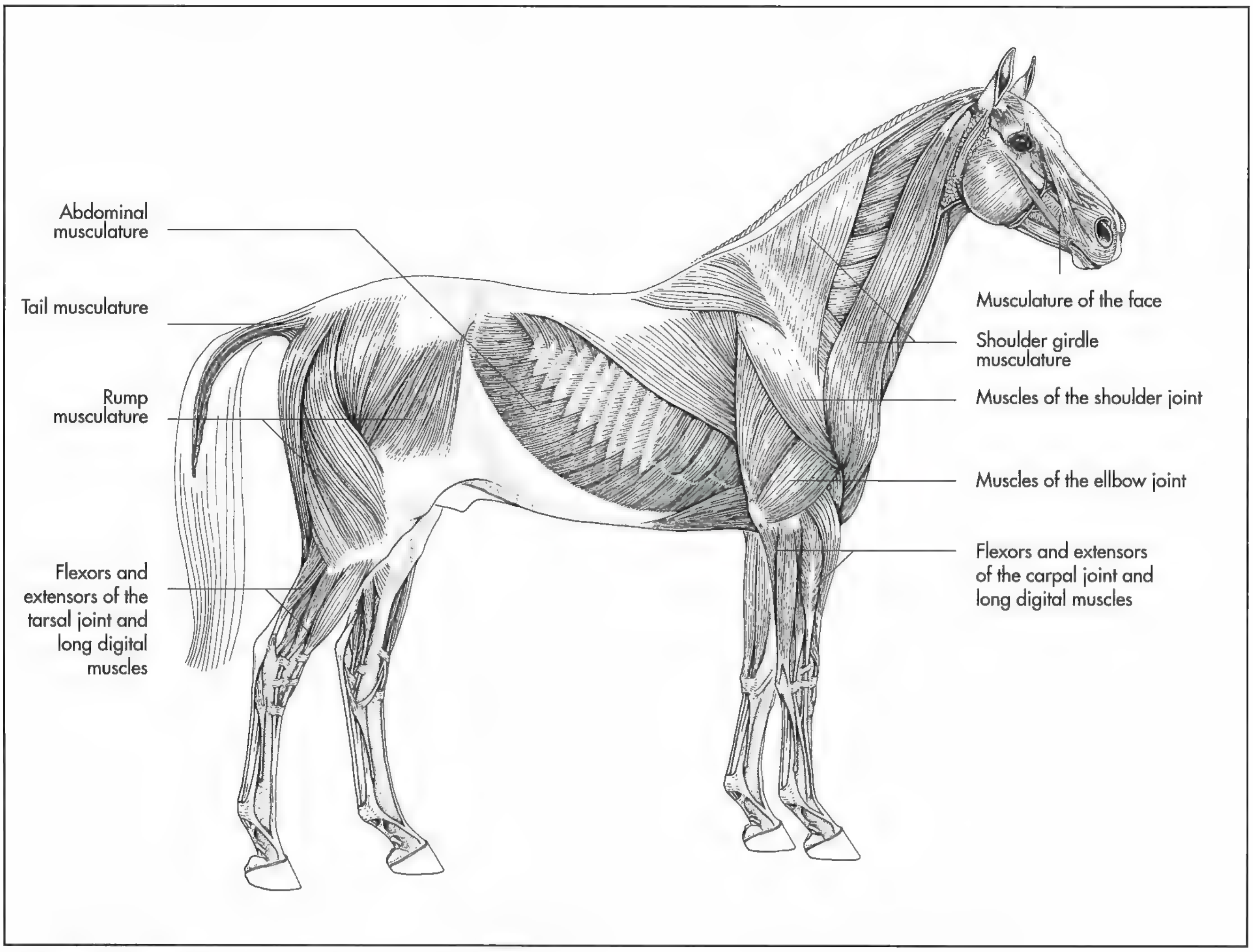

Fig. 0-39. Superficial musculature of the horse (schematic).

- Spindle-shaped muscle (m. fusiformis),
- Sheet-like muscle (m. planus),
- Two-headed muscle (m. biceps),
- Three-headed muscle (m. triceps),
- Four-headed muscle (m. quadriceps),
- Two-bellied muscle (m. biventer seu digastricus),
- Ring-shaped muscle (m. orbicularis) and
- Ring-shaped muscle, which constricts the opening it surrounds (m. sphincter).

Function of muscles in locomotion

Each movement of a body part or the whole body is produced by involvement of several muscles either simultaneously or one after another. Muscles, which have the same effect are called **synergists.** The muscles responsible for the opposite action are known as **antagonists.** During muscle contraction one attachment will maintain static **(punctum fixum),** while the other will be drawn towards the first **(punctum mobile).** The action of a muscle depends on its origin, course, insertion and point of rotation (hypomochlion).

Most natural movements (such as breathing, walking, trotting or galloping) follow a certain rhythm in which contraction and relaxation of muscles alternate in a controlled manner.

Skeletal muscle is in a continuous state of minimal contraction (tone) through reflex action caused by the muscle spindles. This muscle tone ensures balance and readiness for action. Tendinous structures support these functions passively. One of the major aims of anaesthesia is to decrease the **tone of a muscle** during surgery.

To produce appreciable movement a muscle must overcome the muscle tone of its antagonist and gravity. Before a muscle belly contracts visibly by shortening of its muscle fibres **(isotonic contraction),** it increases its intrinsic tension **(isometric contraction).**

The effects a muscle exerts on a joint follow the mechanical laws of lever systems. According to the number of joints they traverse, muscles can be grouped into:

- Uniarticular muscles,
- Biarticular muscles and
- Polyarticular muscles.

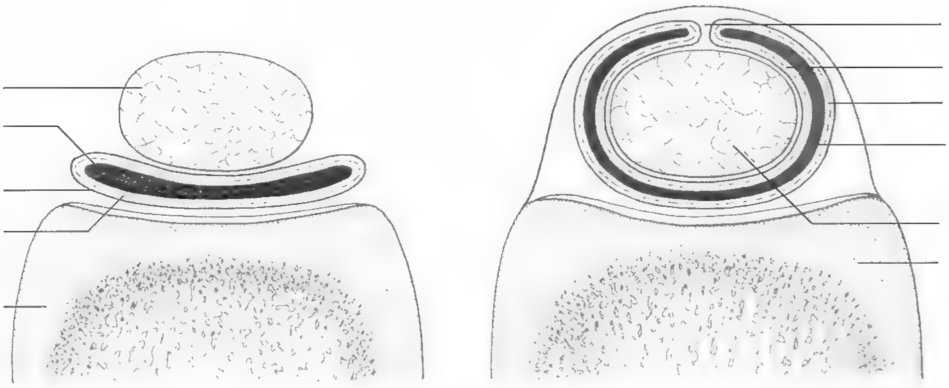

Fig. 0-40. Synovial structures associated with muscles, synovial bursa **(A)** and synovial tendon sheath **(B)** (schematic).

By means of bi- or polyarticular muscles some joints are obligatory linked in their action, some are only linked together under certain circumstances.

Based on their function muscles can be classified as:

- Extensor
- Flexor
- Adductor
- Abductor
- Supinator
- Pronator
- Sphincter
- Dilatator
- Levator
- Depressor
- Rotator

In this chapter schemes of the superficial musculature of the domestic mammals are shown as an introduction to myology (Fig. 0-35 to 0-39). Topography, form and function of the individual muscles are described in later chapters in detail.

Accessory structures (fasciae, tendon sheath and bursae)

Associated with muscles are accessory structures of the locomotor system which support the muscles passively:

- Fasciae,
- Bursae and
- Tendon sheaths (vaginae synoviales tendinum).

Fasciae are thin, expansive soft tissue sheets, enclosing individual muscles or muscle groups. They consist of a mesh of collagen and some elastic fibres, arranged to withstand a maximum of stress and strain. This architecture allows the fascia to adapt to the changing thickness of muscles. Fasciae allow neighbouring organs to change in shape and move easily against each other and provide origin and attachment for muscles. In many places fasciae divide to form septa which penetrate between muscular tissue (septa intermuscularis). Localised thickenings of the fasciae form bands to hold tendons in place at the flexor or extensor sides of joints **(retinacula tendinum).** Fascia are spread over the whole body and can be divided into a thinner superficial layer and a stronger, deep layer. The **superficial fascia** (fascia superficialis) includes the **cutaneous muscle** (mm. cutanei) in some body regions, the **deep fascia** (fascia profunda) is strengthened by yellow coloured elastic fibres, particularly in the horse (tunica flava).

Synovial bursae (bursae synoviales) are soft tissue sacs filled with synovial fluid (Fig. 0-40). They distribute pressure over a larger area, thus protecting the structure they are associated with. Similar to joints, the wall of a bursa consists of two layers, the external **fibrous layer** (membrana fibrosa) and the internal **synovial membrane** (membrana synovialis). They can be divided into several compartments in different areas of the body.

Synovial bursae are located at sites, where muscles, tendons or ligaments pass over hard tissues or change direction over bony prominences. Inconsistent subcutaneous bursae may develop at various sites in response to undue pressure or friction. Synovial bursae can be grouped according to their location:

- Subtendinous bursae (bursae synoviales subtendinosae),
- Submuscular bursae (bursae synoviales submusculares),
- Subligamentous bursae (bursae synoviales subligamentosae) and
- Subcutaneous bursae (bursae synoviales subcutaneae).

Synovial tendon sheaths (vaginae synoviales tendinum) (Fig. 0-34) are double-layered, elongated tubes which enclose tendons. The tendon sheath with its contained synovia reduces friction during movement and protects the tendon against pressure. Sometimes recesses of the synovial membrane of a joint may surround tendons, which are close to the joint.

The **cavity of the tendon sheath** is filled with **synovial fluid.** The synovial membrane of the tendon sheath consists of a **visceral layer** against the tendon and an external **parietal**

layer. The two layers are connected by a thin double layer (mesotendineum), which provides passage for nerves and blood vessels. The mesotendineum more or less disappears where movement and pressure are great or may be represented by threads (vincula tendinum).

Functions of the synovial membrane

The wall of a tendon sheath is responsible for filtration of fluids, diffusion of water-soluble material and active transport of macromolecules. The fluid exchange between the synovial cavity of the tendon sheath and the surrounding soft tissue is regulated by the osmolarity of the synovial fluid and the hydrostatic pressure. Folds and villi, which are formed by the synovial membrane and project into the cavity, have slit-like openings through which this exchange takes place. The surrounding soft tissue includes numerous blood and lymphatic vessels, which influence the function of the tendon sheath considerably. A physiological equilibrium is reached, when the amount of filtrated synovial fluid equals the amount of fluid reabsorbed. Inflammation of the wall of the tendon sheath causes a severe disturbance of the equilibrium and results in an swelling of the diseased structure. The lymphatic drainage is of special importance in the regulation of the hydrostatic pressure, since excessive fluid is drained via lymphatic vessels, assisted by rhythmic contraction of the musculature.

Some **clinical expressions,** which are related to anatomical terms:

Osteopathy, ostitis, osteomyelitis, periostitis, osteosynthesis, osteolysis, osteomyelofibrosis, osteonecrosis, osteoperiostitis, ossificans, osteopetrosis, osteoporosis, osteochondrosis, osteosarcoma, arthropathia, arthritis, arthrosis, arthroscopy, arthrolysis, hip dysplasia, myopathy, myodistrophy, myofibrosis, myometritis, myocarditis, myospasm, tendopathy, tendinitis, bursitis, synovitis.

1 Axial skeleton (skeleton axiale)

H.-G. Liebich and H. E. König

The axial skeleton comprise the:

- Skeleton of the head,
  - Skull,
  - Neural part (cranium, neurocranium),
  - Facial part (facies, viscerocranium),
  - Mandible,
  - Hyoid apparatus,
  - Ossicles of the middle ear,
- Vertebral column and
- Skeleton of the thorax.

Skull

The skull forms a rigid construction composed of many bones, which are mostly paired. It encompasses and protects the brain and the sensory organs of sight, smell, sound, balance and taste. It also lodges part of the upper respiratory and alimentary tracts. Bony projections form attachments for the facial and masticatory musculature.

The individual bones of the skull are firmly united by **sutures** (suturae), whereas the **lower jaw** (mandible) and the **hyoid apparatus** (apparatus hyoideus) are attached to the skull by articular joints (Fig. 1-1, 2, 34 to 39).

Few bones of the head have their embryological origins in the **axial skeleton,** the majority are ossified structures of a **dermal skeleton.** The bones derived from the dermal skeleton develop by membranous ossification and cover the lateral and dorsal aspects of the brain, whereas the bones of the axial skeleton develop by endochondral ossification and form the base of the skull and parts of the facial skull.

The **individual bones** develop from **separate centres of ossification.** In young animals they are divided by strips of fibrous, or less often, cartilagenous tissue. This form of development provides the adaptability of the skull for postnatal growth. In the newborn, the facial part of the skull is comparatively small, due to the disproportionate small size of the masticatory apparatus, the nasal cavities and the paranasal sinuses. In the post-natal period, the proportions of the skull change.

This is due to the species-specific development of the roof of the skull and the individual bones and also the enlargement of the skull as a whole, which is significantly influenced by the growth of the teeth, the formation of the paranasal sinuses and the elongation of the base of the skull. This remodelling is a long process, which continues for some structures of the skull throughout the whole life.

Vertebral column or spine

The bony components of the vertebral bodies are derived from the axial, perichondral mesenchymal of the sclerotomes. The **intervertebral discs** (disci intervertebrales) are considered to be remnants of this original tissue. The embryological precursor of the vertebral body forms a bony arch dorsally, thus completing the central **foramen of the vertebra** (foramen vertebrae), which encloses the spinal cord.

The individual vertebrae are joined together by articular processes and ligaments. The vertebral column as a whole consists of a series of separate bones, the vertebrae, which extend from the skull to the tip of the tail. Starting with the **foramen magnum** at the skull and ending with the **sacral canal** (canalis sacralis), the vertebral foramina of the single vertebrae sum up to constitute the **vertebral canal** (canalis vertebralis), which encompasses the spinal cord (medulla spinalis), its meninges, the spinal nerves (nervi spinales), blood vessels and connective tissue. The separate vertebrae are not joined rigidly together, but have spaces between them (spatia intervertebralia) for the passage of the spinal nerves.

Along the long axis of the vertebral column **three major curvatures** are recognised:

- Dorsal convex curvature between the head and neck,
- Dorsal-concave curvature between the cervical and thoracic spine,
- Dorsal-convex curvature between the thoracic lumbar spine.

The vertebral column serves to support the body and takes over a central function as part of the locomotor system by forming a bridge between the thoracic and pelvic limbs. The cranial thoracic vertebrae of the vertebral column are supported by the ribs, which are linked to the thorax by muscles and tendons. This anatomical arrangement provides stability and mobility for the vertebral column. In the region of the pelvis the vertebral column is firmly joined to the pelvic limb by the articulation of the **sacral wings** to the **ilia.** Thus the propel-

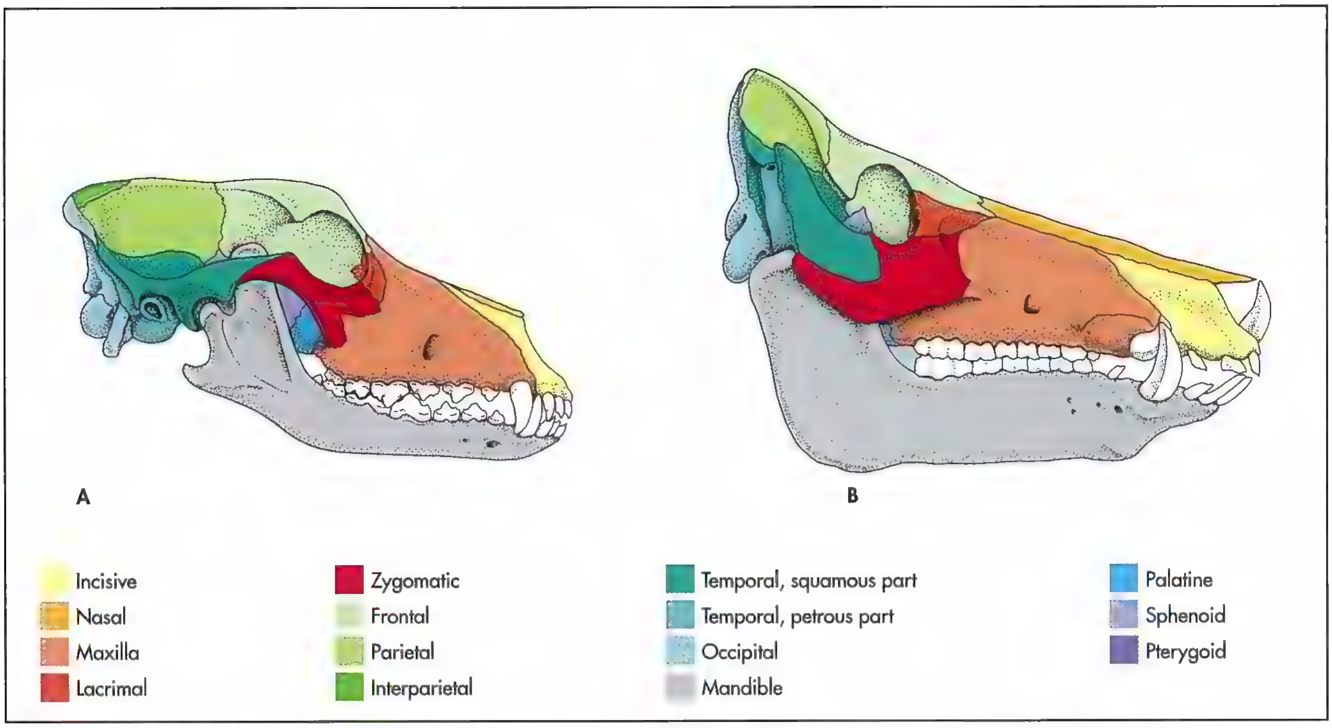

Fig. 1-1. Bones of the skull and mandible of the dog **(A)** and pig **(B)**, (schematic, lateral aspect) (Ellenberger and Baum, 1943).

ling force of the hindlimb, generated by the muscles and the hip joint, is transmitted directly to the rest of the body.

The vertebral column fulfills various additional functions. As movement between the individual vertebrae is limited, it contributes to the maintenance of posture. However, the degree of movability of the individual vertebrae forms the basis for dynamic functions, including the transmission and reduction of forces during walking, running and jumping. The smallest functional unit consists of two successive vertebrae, the intervertebral disc, their articulations, ligaments and muscles. Even small anatomical changes of one of the components will result in a significant disturbance of the locomotory system. The movability of the vertebral column varies in the different segments for example, it is very rigid in the region of the sacrum, while the caudal vertebrae remain quite flexible.

The vertebral column in the thoracic and lumbar region allows movement in three directions. Small movements of the individual intervertbral joints cause dorsal, ventral and lateral flexion of the whole column. Considerable lateral, dorsal and ventral movements are possible in the neck.

Thorax

The rib cage is composed of the **thoracic vertebrae** (vertebrae thoracicae) dorsally, the **ribs** (costae) laterally and the **sternum** ventrally. They form the bony components of the thoracic wall and are joined functionally by a variety of ligaments, chondral junctions and true articulations. The rib cage encloses the **thoracic cavity** (cavum thoracis) and is kept under tension by its surrounding muscles. The thorax of the domestic mammals has the shape of a laterally compressed, truncated cone, with its apex pointing cranially and its base caudally. It has a **cranial** and a **caudal aperture** (apertura thoracis cranialis et caudalis).

Skeleton of the head

Skull, neural part (cranium, neurocranium)

The bones of the neural or cranial part of the skull enclose the **cranial cavity** (cavum cranii), including the brain, its meninges and blood vessels. The structure of the cranium is a collection of many smaller bones, that fit together in a species specific construction. Skulls differ largely, not only between different species and breeds, but also between individuals of the same breed, age and sex. The basic anatomical architecture of the neural part of the skull will be described, with species specific variations emphasised. The cranium is formed by the same bones in all domestic mammals:

- **The floor is composed of the**
  - Unpaired basioccipital bone (pars basilaris ossis occipitalis),
  - Unpaired basisphenoid and presphenoid bones (os basisphenoidale et os presphenoidale).
- **The nuchal wall is composed of the**
  - Unpaired supraoccipital bone (squamous part, squama occipitalis),
  - Paired exoccipital bones (lateral parts, Partes laterales).

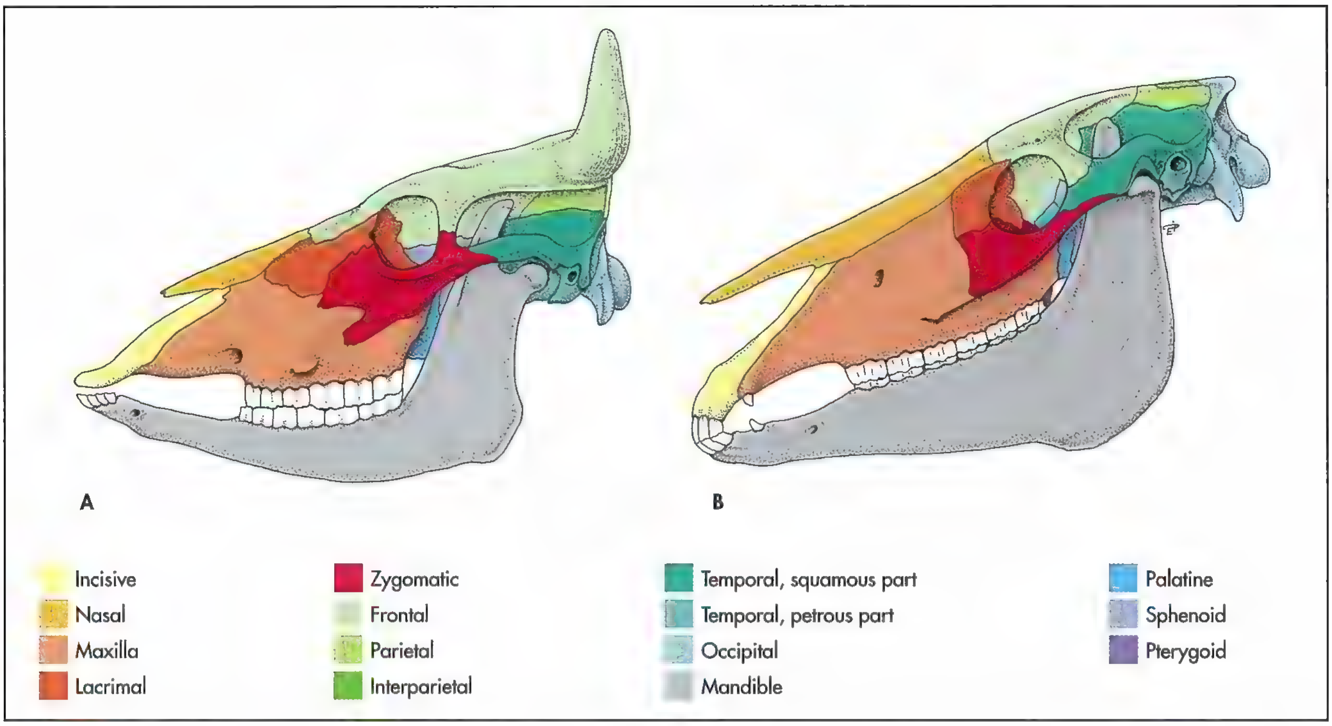

Fig. 1-2. Bones of the Bones of the skull and mandible of the ox **(A)** and horse **(B)**, (schematic, lateral aspect) (Ellenberger and Baum, 1943).

- **The lateral walls are composed of the**
  - Paired temporal bone (os temporale).
- **The roof is composed of the**
  - Paired frontal bone (os frontale),
  - Paired parietal bone (os parietale),
  - Unpaired interparietal bone (os interparietale).
- **The nasal wall is composed of the**
  - Unpaired ethmoid bone (os ethmoidale).

Occipital bone (os occipitale)

The occipital bone forms the nuchal wall of the skull and can be divided into the **basilar part,** the **squamous part** and the **lateral parts** (Fig. 1-1, 2, 6-8). These bones form a ring, surrounding the spinal cord, the **foramen magnum.**

The **basilar part** (pars basilaris, basioccipital bone) constitutes the caudal part of the base of the cranium. It is situated rostral to the foramen magnum, where it is joined to the basisphenoid by a cartilagenous suture (Fig. 1-6). On the ventral surface are the paired **muscular tubercles** (tubercula muscularia) for the attachment of the flexors of the head and neck. The surface of the cranium is concave, forming the **caudal cranial fossa** (fossa cranii caudalis), which is subdivided into rostral and caudal depressions. The rostral depression encompasses the pons (impressio pontina) and the caudal depression encompasses the medualla oblongata (impressio medullaris) (Fig. 1-5).

The **jugular foramen** (foramen jugulare) is located either side of the basilar part, adjacent to the tympanic bullae. In the pig and the horse the sharp and thin lateral borders of the basilar part form the deep petrooccipital fissure (fissura petrooccipitalis) together with the petrosal part (pars petrosa) of the temporal bone where the foramen lacerum is built (Fig. 1-60 and 61).

The **squamous part** (pars squamosa, supraoccipital bone) is situated dorsal to the **lateral parts** (partes laterales ossis occipitalis) and the **occipital condyles** (condyli occipitales), completing the foramen magnum dorsally (Fig. 1-7 and 8). Its **external surface** (lamina externa) is demarcated by a sharp-edged ridge, the **nuchal crest** (crista nuchae) (Fig. 1-3, 4 and 7). In ruminants, the nuchal crest is reduced to the prominant **nuchal line** (linea nuchae). The nuchal crest is easily palpable and can be used as a landmark, together with the wings of the atlas, for the collection of cerebrospinal fluid.

The well-defined median ridge, the **external sagittal crest** (crista sagittalis externa), arises from the nuchal crest in carnivores and the horse (Fig. 1-3, 19 and 20). The **external occipital protuberances** (protuberantia occipitalis externa) are median triangular projections with the base pointing towards the base of the cranium, and provide attachments for the **nuchal ligament** (ligamentum nuchae) (Fig. 1-7 and 8). In carnivores, the poorly defined **external occipital crest** (crista occipitalis externa) extends from the external occipital protuberance to the foramen magnum.

The **internal surface of the cranium** (lamina interna) has many shallow depressions, which conform to the surface of the cerebellum (impressiones vermiales) and the basal blood vessels (sulci sinus transversi). The internal surface is marked by the **internal occipital protuberance** (protuberantia occipitalis interna) (Fig. 1-11). Carnivores and horses have an additional process, the tentorial process (processus tentoricus), which forms the osseous tentorium cerebelli (Fig. 1-5), together with like-named processes of the parietal and interparietal bones.

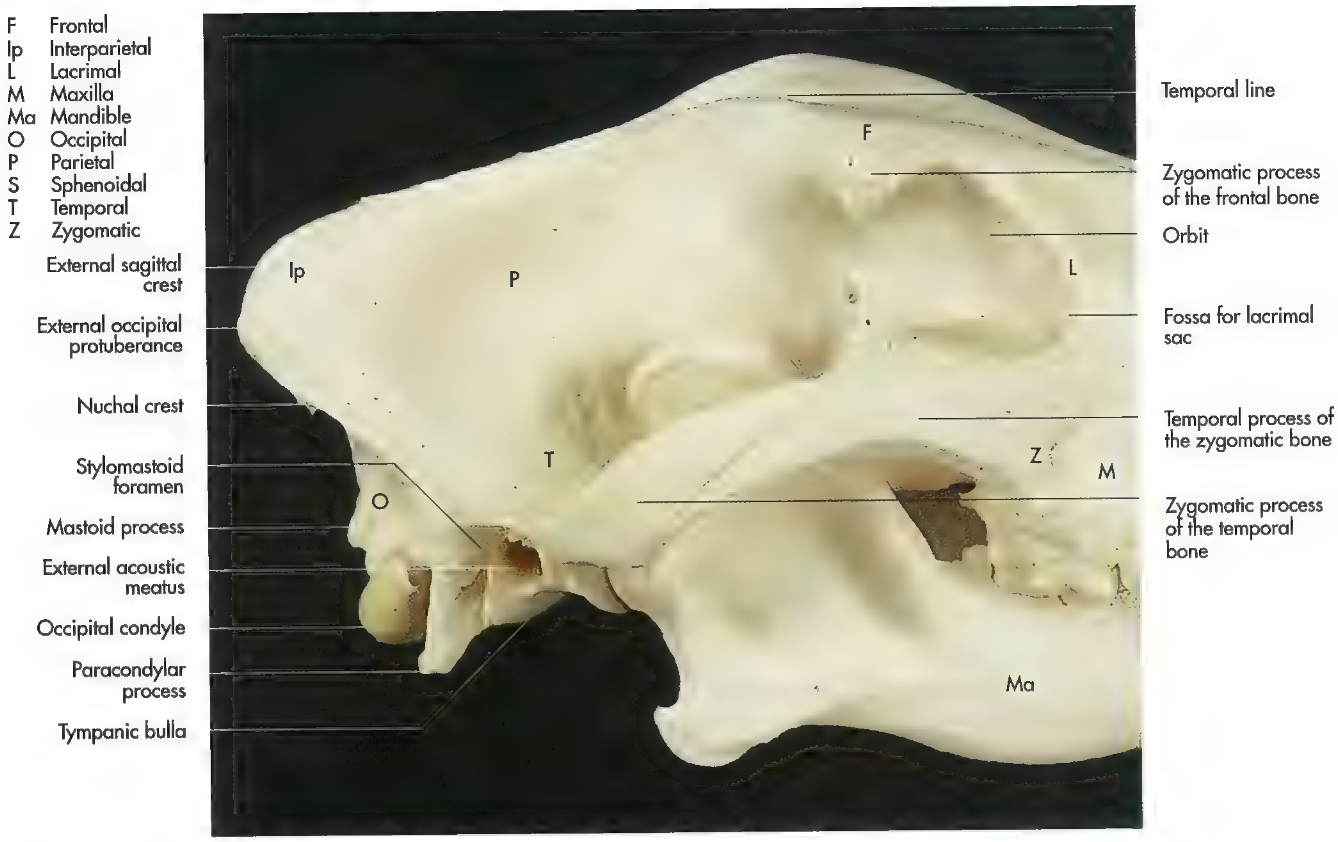

Fig. 1-3. Cranial part of a canine skull (lateral aspect).

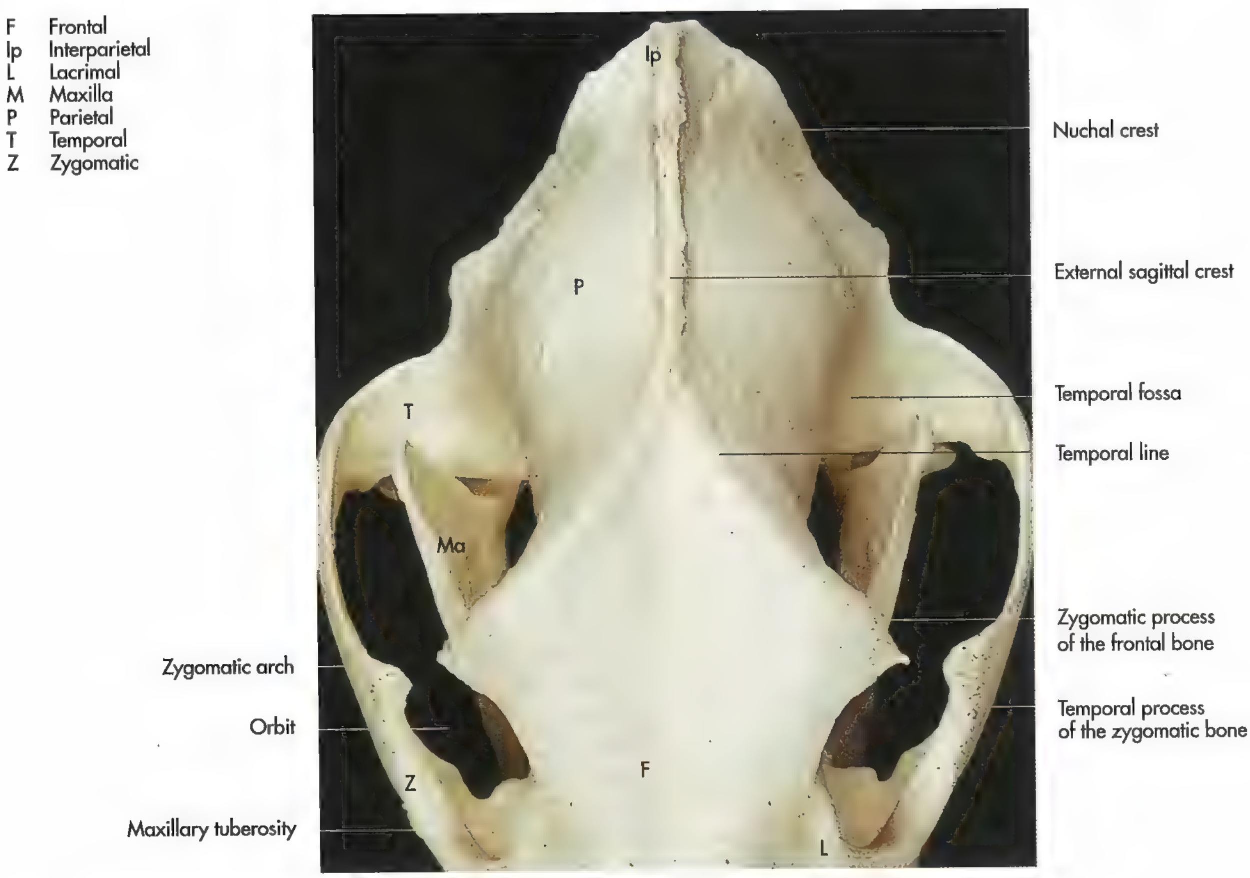

Fig. 1-4. Bones of the cranial part of a canine skull (dorsal aspect).

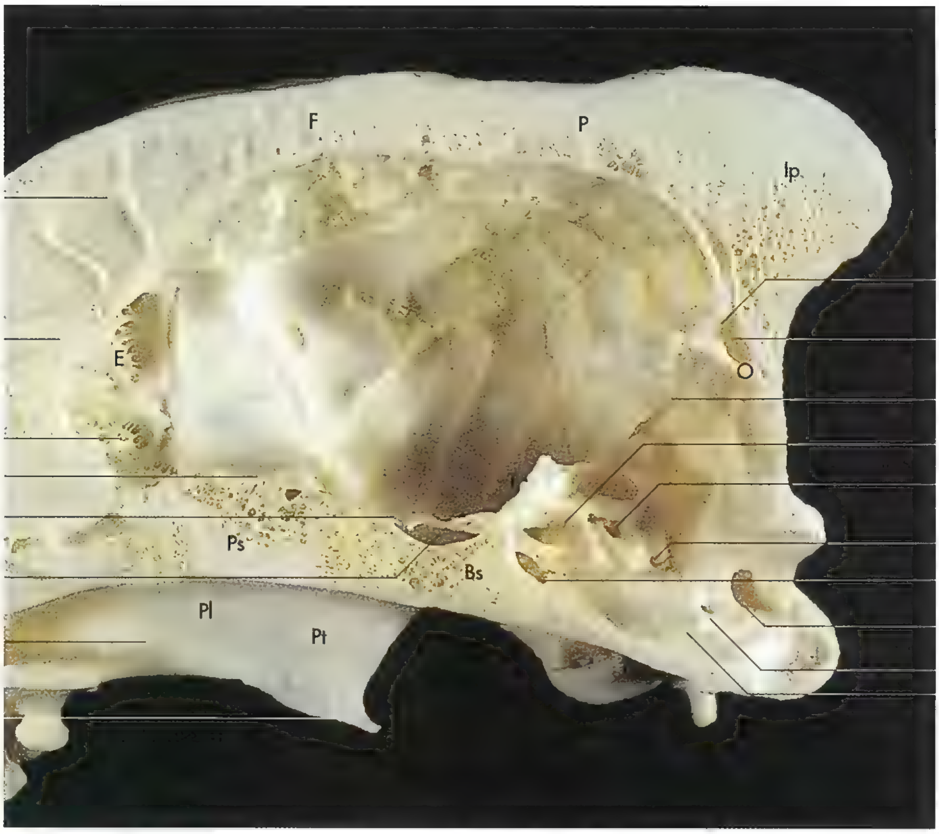

Fig. 1-5. Bones of the cranial part of a canine skull (medial aspect of sagittal section).

Fig. 1-6. Bones of the cranial part of a canine skull (ventral aspect).

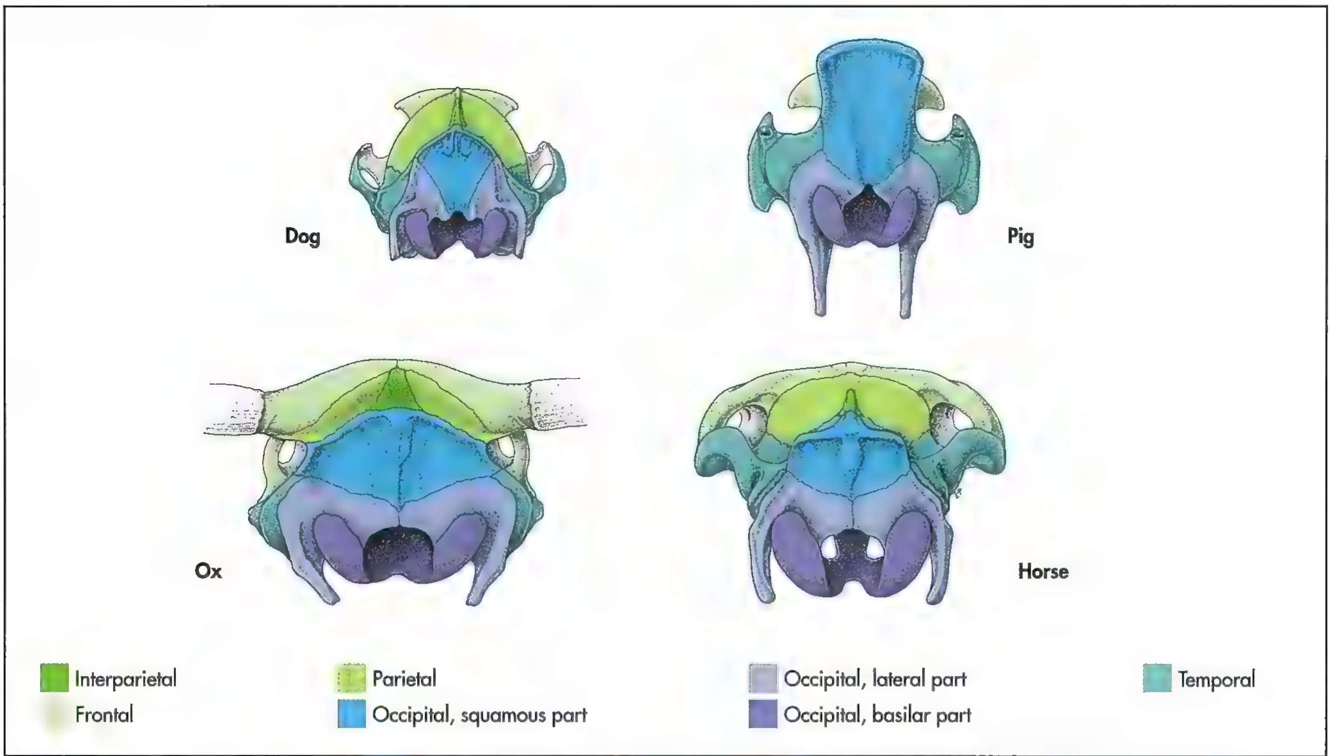

Fig. 1-7. Nuchal aspect of the canine, porcine, bovine and equine skull (schematic) (Ellenberger and Baum, 1943).

The **lateral parts of the occipital bone** (partes laterales, exoccipital bones) form the lateral borders of the foramen magnum. They include the **occipital condyles** (condyli occipitales), which articulate with the atlas to form the atlanto-occipital joint (Fig. 1-3 and 6). Lateral to the condylar process, the **paracondylar processes** (processus paracondylares), provide attachment to the specific muscles of the head (as described in Chapter 2).

These processes are elongated in the pig, shorter in ruminants and the horse and bulb-shaped in carnivores (Fig. 1-3 and 6). They are thought to be rudimentary transverse processes analogous with those of the cervical vertebrae. The ventral **condyloid fossa** (fossa condylaris ventralis), which forms the end of the **hypoglossal canal** (canalis nervi hypoglossi), through which the hypoglossal nerve passes, is located between the paracondylar and the condylar process (Fig. 1-6 and 12). This fossa is continuous with the **dorsal condylar fossa** (fossa condylaris dorsalis).

Sphenoid bone (os sphenoidale)

The **sphenoid bone** forms the rostral part of the base of the neurocranium and consists of two similar segments, the **presphenoid** (os praesphenoidale) rostrally and the **basisphenoid** (os basisphenoidale) caudally (Fig. 1-6 and 12).

Each bone is composed of a **median body** (corpus ossis sphenoidalis) and **wings** (alae ossis sphenoidalis) laterally. In humans these bones fuse firmly in early life, while in adolescent domestic mammals they are separated by a cartilagenous suture, which ossifies in the adult. Therefore they are considered as individual bones in veterinary anatomy.

Presphenoid (os praesphenoidale)

The **body** and **wings of the presphenoid** (corpus et alae ossis praesphenoidalis) consitute the bony parts of the **rostral cranial fossa** (fossa cranii rostralis) and articulate with the basisphenoid caudally (Fig. 1-13). The body of the presphenoid is hollow and encloses the paired **sphenoid sinuses** (sinus sphenoidales), which are separated by an incomplete septum (Fig. 1-21). The beak-shaped **sphenoidal rostrum** (rostrum sphenoidale) projects from the body rostrally towards the ethmoid. Just caudal to this, there is a transverse depression (sulcus chiasmatis) on which the **optic chiasma** (chiasma opticum) rests. The bony **optic canal** (canalis opticus) extends from each end of this groove over the wings of the presphenoid through which the optic nerve passes (Fig. 1-11 and 13).

The external surface of the **wings of the presphenoid** (alae ossis praesphenoidales) contribute to the formation of the orbit and the optic canal, whereas the internal surface forms part of the cranial cavity.

Basisphenoid (os basisphenoidale)

The **body** and **wings of the basisphenoid** (corpus et alae ossis basisphenoidalis) consitute the bony parts of the **medial cranial fossa** (fossa cranii rostralis), which includes the **tuberculum sellae** (sella turcica) rostrally, the **hypophyseal fossa** (fossa hypophysialis) in the middle and the **dorsum sellae** (dorsum sellae turcicae) (with the exception of the horse) caudally (Fig. 1-13). The surfaces of the **wings of the basisphenoid** (alae ossis basisphenoidalis) oppose the brain (facies cerebralis), the temporal bone (facies temporalis), the max-

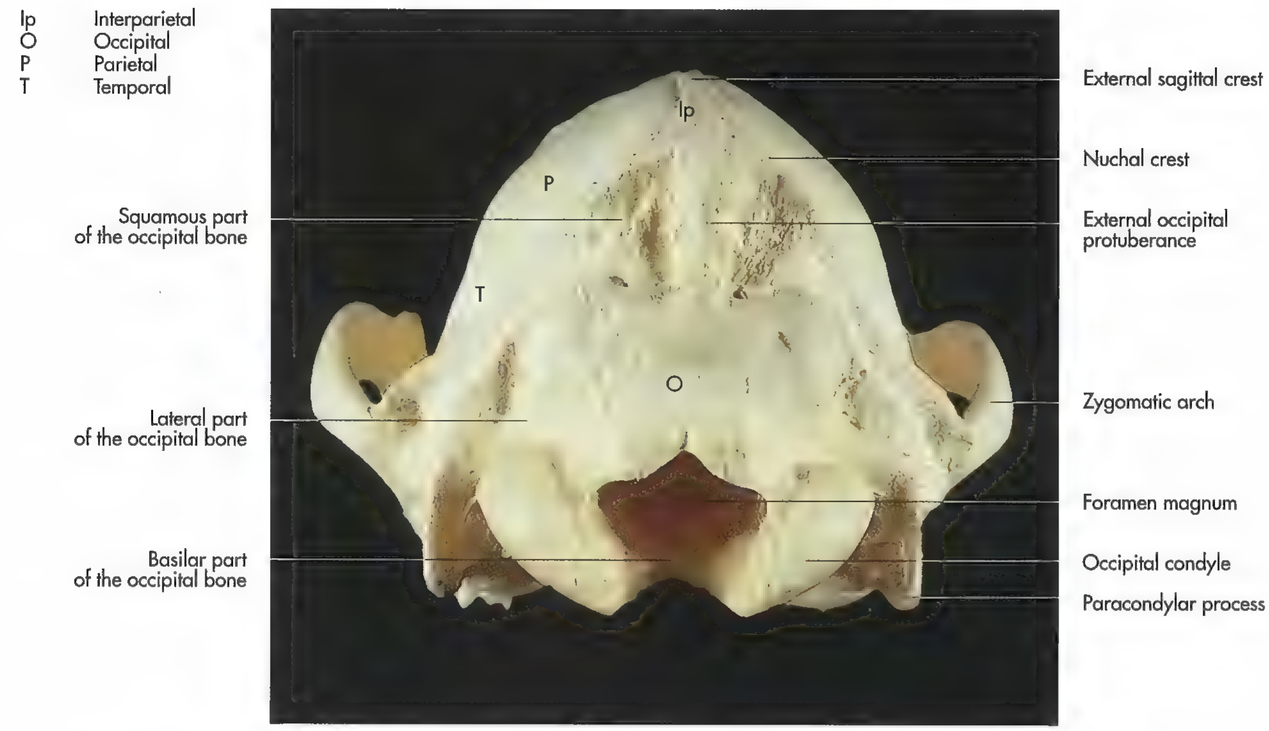

Fig. 1-8. Nuchal aspect of a canine skull.

illa (facies maxillaris) and the orbit (facies orbitalis). The piriform fossae are located lateral to the optic groove and encompass the piriform lobes (lobi piriformes) of the brain. Each wing contributes to the formation of various foramina and notches for the passage of nerves and blood vessels with species-specific variations.

In the horse, the caudal border of each wing forms the rostral border of the foramen lacerum: It forms three notches, the **carotid notch** (incisura carotica) for the passage of the internal carotid artery medially, the **oval notch** (incisura ovalis) for the passage of the mandibular nerve and **the spinous notch** (incisura spinosa) for the middle meningeal artery laterally. The foramen lacerum is absent in carnivores and ruminants and its functions are replaced by the **oval foramen,** the **spinous foramen** and the carotid canal in carnivores and by a oval foramen only in ruminants (Fig. 1-6 and 17).

The **pterygoid processes** (processus pterygoidei) arise from the rostral border of the basisphenoid. They project ventro-rostrally and form the boundaries of the choanae, together with the palatine and pterygoid bones (Fig. 1-5). The base is perforated by the **alar canal** (canalis alaris), through which the maxillary artery passes. It originates with the **caudal alar foramen** (foramen alare caudale) and terminates with the **rostral alar foramen** (foramen alare rostrale).

Temporal bone (os temporale)

The temporal bone of the newborn animal consists of three distinct parts, which unite later in life:

- Squamous part (pars squamosa, squama temporalis, squamosa),
- Petrosal part (pars petrosa, petrosum) with its mastoid process (processus mastoideus) and
- Tympanic part (pars tympanica).

The petrosal and tympanic parts are sometimes also called the pyramid and are firmly fused to the squamous part in carnivores and in the ox, but remain separated in the other domestic mammals.

The **cerebral surface** (facies cerebralis) of the **squamous part** (pars squamosa, squama temporalis, squamosum) contributes to the formation of the lateral wall of the cranial cavity. It unites with the frontal, parietal and sphenoid bones in firm osseous sutures.

The long **zygomatic process** (processus zygomaticus) arises from the temporal surface (facies temporalis) of the squamous part. It extends rostrolaterally to unite with the **temporal process of the zygomatic bone,** forming the **zygomatic arch** (arcus zygomaticus) (Fig. 1-3, 4 and 10). The base of the zygomatic process expands to form the articulating surface of the **temporomandibular joint** (articulatio temporomandibularis). This articulating surface consists of a transversely elongated **articular tubercle** (tuberculum articulare) rostrally and the **mandibular fossa** (fossa mandibularis) caudal to it.

The mandibular fossa is deliniated caudally by the **retroarticular process** (processus retroarticularis) (Fig. 1-12). While the articular tubercle is missing in carnivores, these species have an especially well-developed retroarticular process (Fig. 1-6).

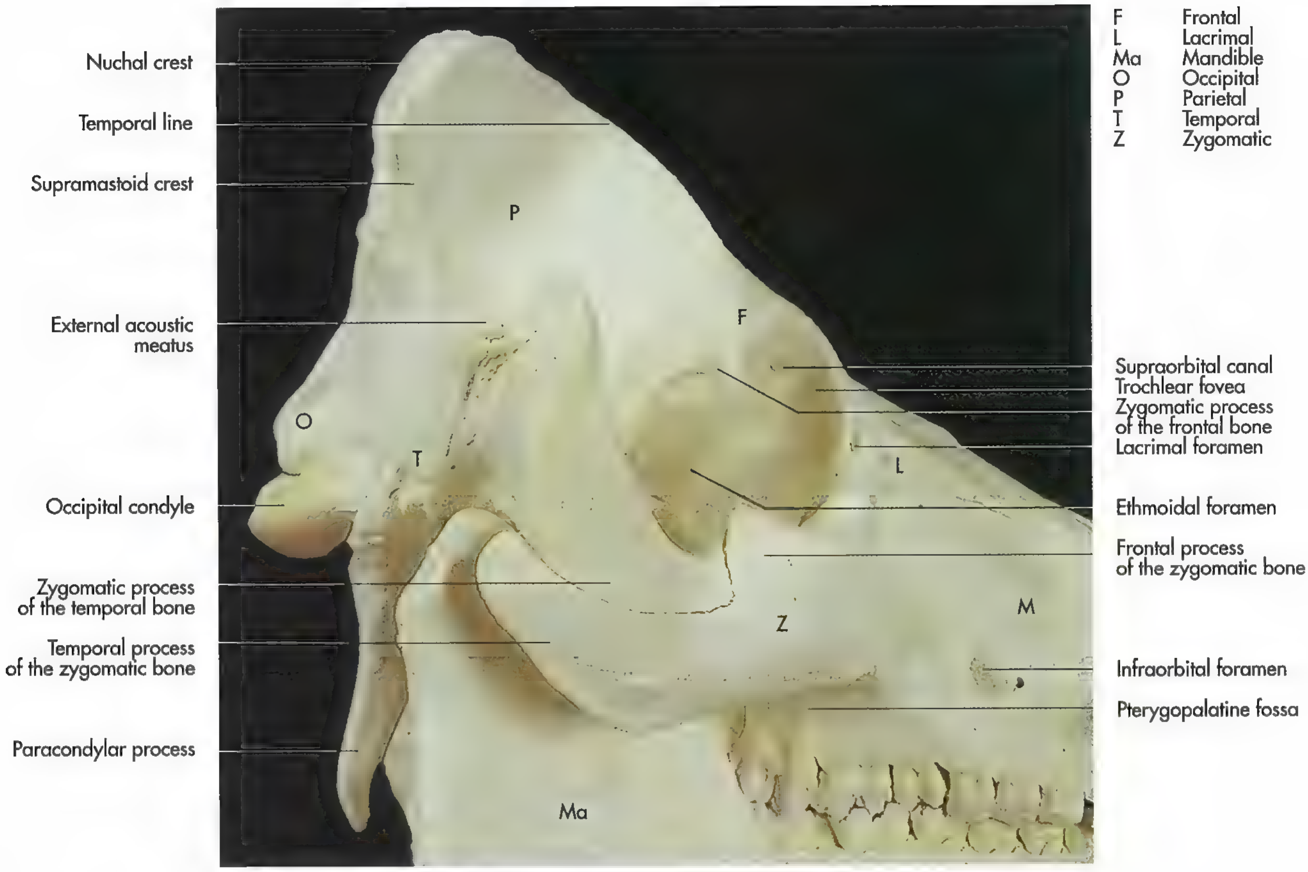

Fig. 1-9. Bones of the cranial part of a porcine skull (lateral aspect).

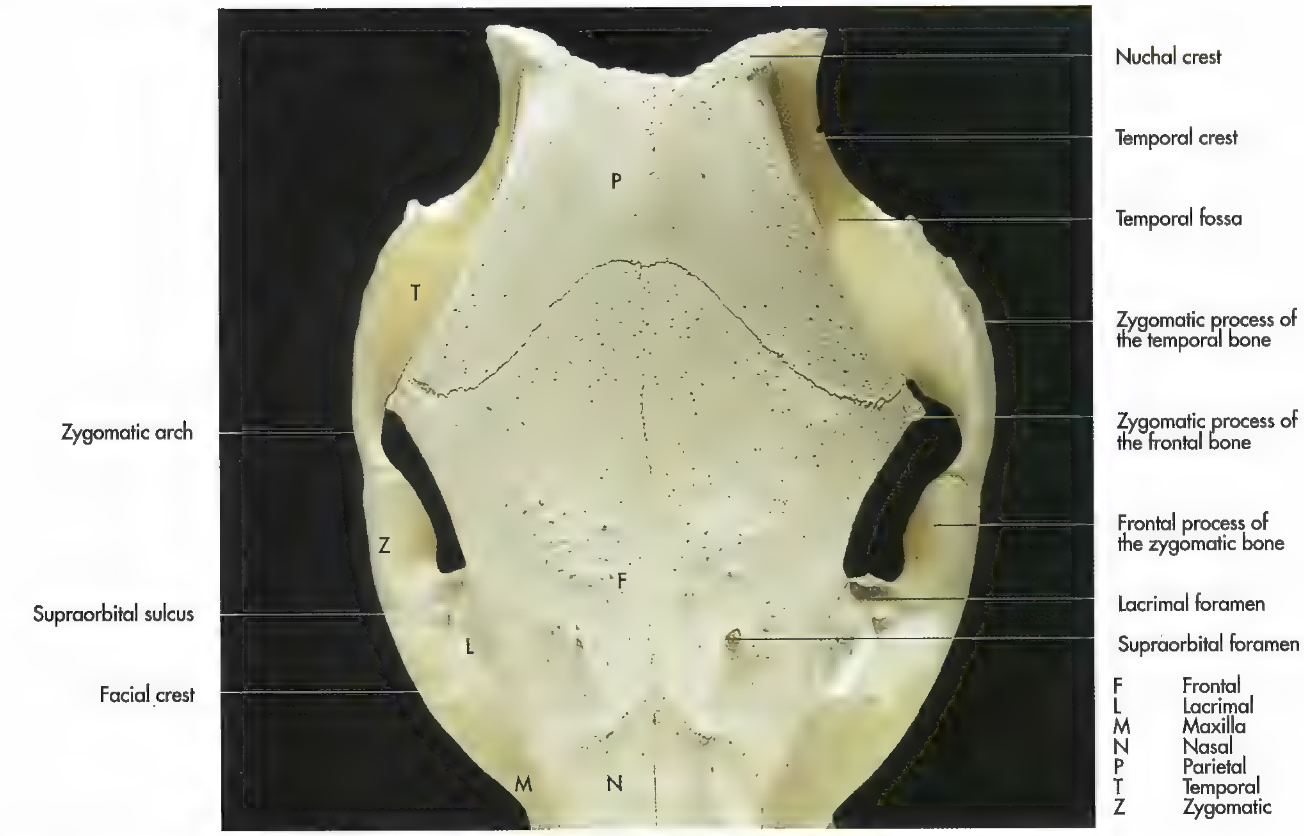

Fig. 1-10. Bones of the cranial part of a porcine skull (dorsal aspect).

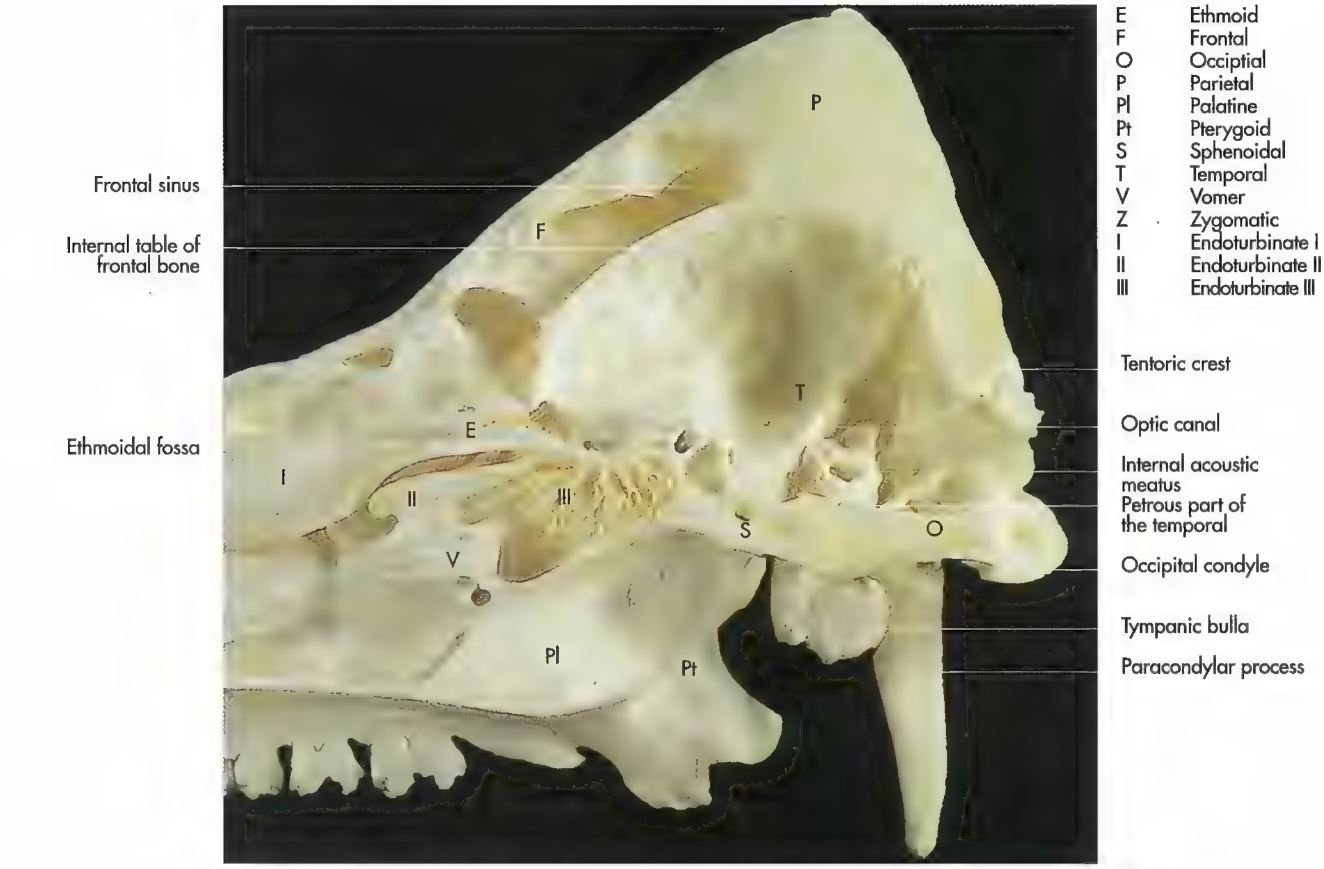

Fig. 1-11. Bones of the cranial part of a porcine skull (medial aspect of sagittal section).

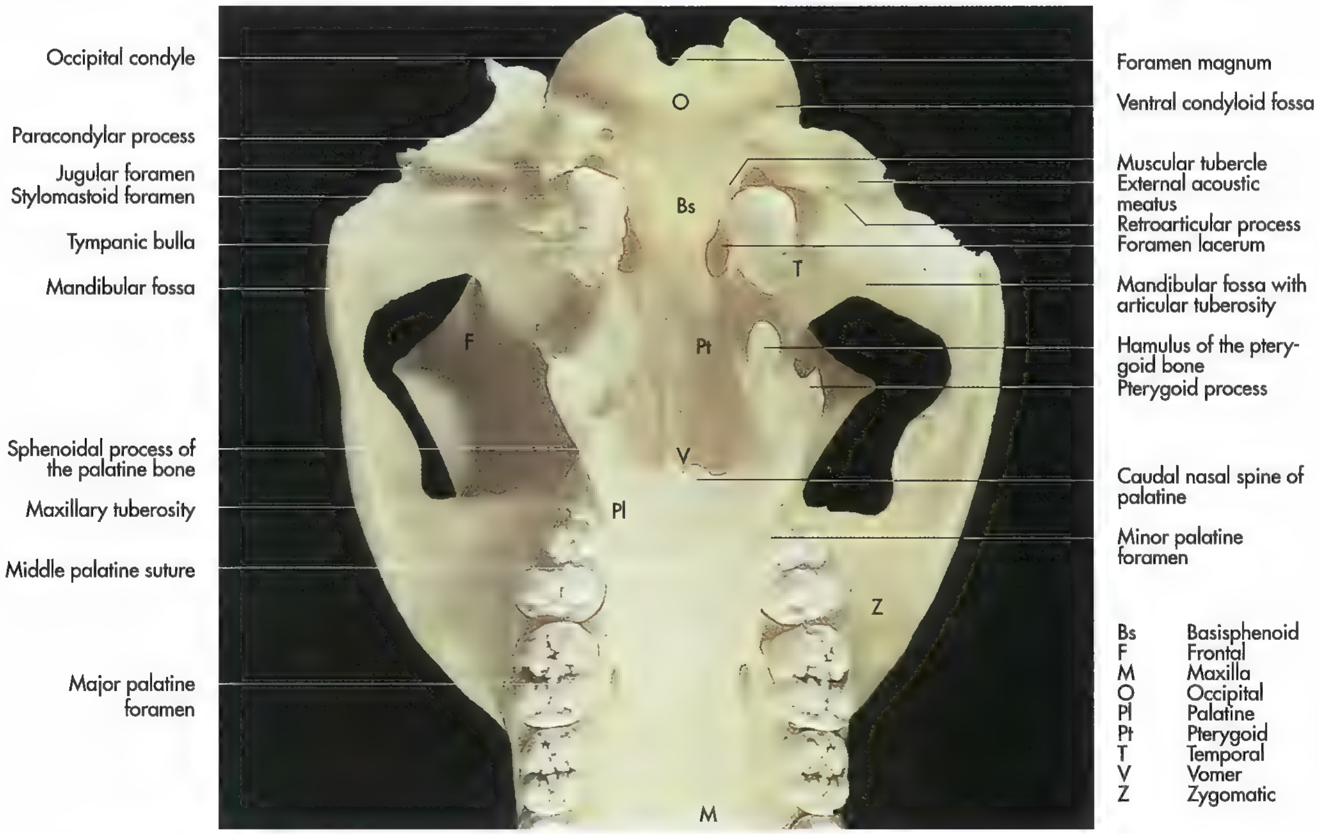

Fig. 1-12. Bones of the cranial part of a porcine skull (ventral aspect).

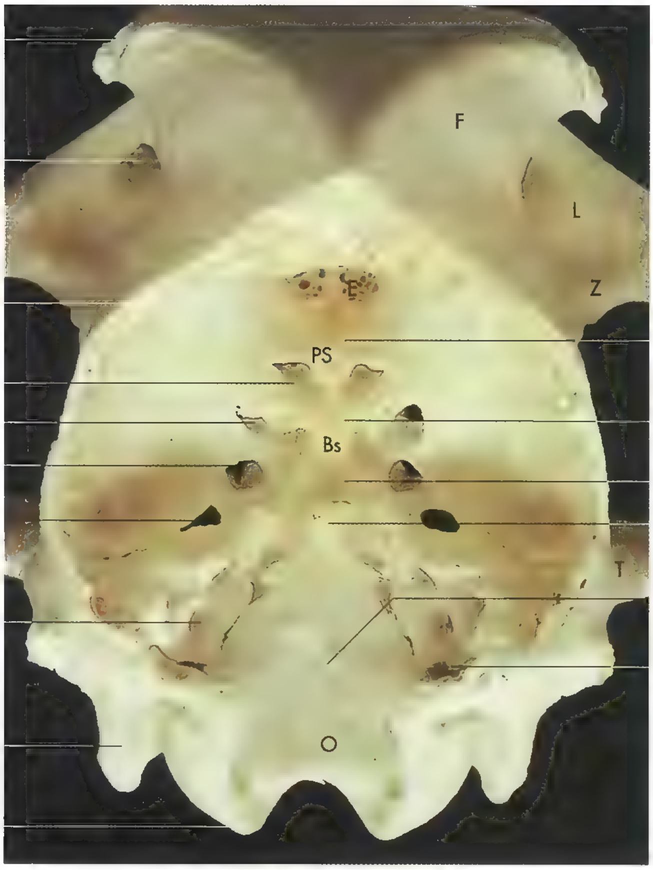

Fig. 1-13. Cranial cavity of a dog with calvaria removed (dorsocaudal aspect).

The caudal part of the squamous part forms the **occipital process** (processus occipitalis), the ventral surface forms the **retrotympanic process** (processus retrotympanicus), which surrounds the **external acoustic meatus** (meatus acusticus externus) caudally. The **retroarticular foramen** (foramen retroarticularis) exits caudal to the latter process and forms the end of the **temporal canal** (meatus temporalis) (Fig. 1-6). The temporal canal is rudimentary in the cat and pig.

The **petrosal part** (pars petrosa, petrosum) is the caudoventral portion of the temporal bone and is bordered by the squamous and the tympanic parts. It encloses the **inner ear** with the **cochlea,** the **vestibule** (vestibulum) and the **semicircular canals** (canales semicirculares). Its medial surface (facies medialis) is perforated by the entrance (porus acusticus internus) of the **internal acoustic meatus** (meatus acusticus internus), through which the cranial nerves of the face, the **facial nerve** (n. facialis) and of hearing and balance, the **vestibulocochlear nerve** (n. vestibulocochlearis) pass (Fig. 1-5 and 11). The rostral and medial surfaces of the petrosal part are separated by the sharp-edged **petrosal crest** (crista partis petrosae) in carnivores and the horse.

Caudally, the petrosal part extends beyond the skull, forming the **mastoid process** (processus mastoideus) ventrally. The mastoid process is a strong, bulb-shaped projection in the horse, whereas it is smaller in the other domestic mammals. Attachment for the **hyoid apparatus** (apparatus hyoideus) is provided by the cylindrical **styloid process** (processus styloideus) in horses and ruminants, which is positioned rostroventral to the external acoustic meatus of the petrosal part (Fig. 1-18 and 22). The styloid process is absent in carnivores and the pig and therefore the hyoid apparatus articulates with the mastoid process of the petrosal part in carnivores (Fig. 1-3 and 6) and the nuchal process (processus nuchalis) of the squamous part, which is located close to the base of the paracondylar process in the pig. The external opening of the facial canal, where the facial nerve emerges, the **stylomastoid foramen** (foramen stylomastoideum) is situated between the styloid and mastoid process in ruminants, the pig and the horse and between the mastoid process and the tympanic part in carnivores (Fig. 1-16).

The **tympanic part** (pars tympanica, tympanicum) is the ventral portion of the temporal bone. Its bulbous enlargement, the **tympanic bulla** (bulla tympanica) encloses the **tympanic cavity of the middle ear** (cavum tympani) (Fig. 1-6, 12, 17 and 22). In the cat, the tympanic cavity is divided into two parts and the medial wall is formed by the cartilagenous precursor of a separate endotympanic part (pars endotympanica).

The **external acoustic meatus** (meatus acusticus externus) opens dorsolaterally (porus acusticus externus) (Fig. 1-18) and is separated from the tympanic cavity by a membranous diaphragm, the **tympanic membrane** or **eardrum** (membrana tympani), which is attached to the **tympanic ring** (anulus tympanicus). The dorsal part of the tympanic cavity encloses the auditory ossicles (ossicula auditus), the stapes, malleus and incus. The **muscular process** (processus muscularis) extends from the mediorostral walls of the tympanic

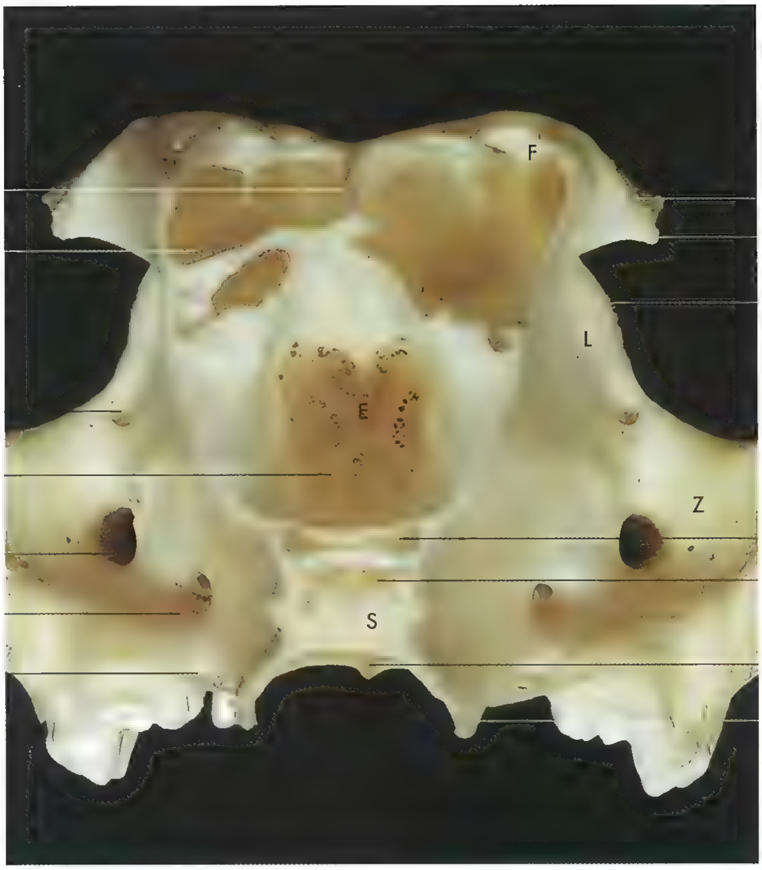

Fig. 1-14. Transverse section of a canine cranial cavity caudal to the zygomatic process of the frontal bone.

bulla. This is especially prominent in horses and ruminants. The groove like auditory tube (semicanalis tubae auditivae) is medial to the muscular process and adjacent to the groove of the tensor veli palatini muscles (semicanalis musculi tensoris veli palatini) in the musculotubal canal (canalis muscolotubarius), which connects the tympanic cavity to the pharynx.

Frontal bone (os frontale)

The paired frontal bones are situated between the cranium and the face and are united in the **interfrontal suture** (sutura interfrontalis). Each frontal bone encloses, depending on the species, one or more air-filled cavities, the frontal sinuses (sinus frontales). Based on their location the frontal bone can be divided in three segments:

- Frontal squama (squama frontalis),
- Orbital part (pars orbitalis),
- Temporal surface (facies temporalis) and
- Nasal part (pars nasalis).

The **frontal squama** is bordered by the nasal and lacrimal bone in large animals and is limited to the wall of the orbital cavity in carnivores. It extends to form the **zygomatic process** (processus zygomaticus) laterally, (Fig. 1-3, 4, 10, 19 and 20), which forms part of the **dorsal margin of the orbit** (margo supraorbitalis) (Fig. 1-16). The zygomatic process articulates in a species-specific way. In ruminants it forms an osseous union with the frontal process of the zygomatic bone (processus frontalis ossis zygomaticum), in horses with the zygomatic process of the temporal bone (processus zygomaticus ossis temporalis). In carnivores the dorsal margin of the orbit is formed by the **orbital ligament** (ligamentum orbitale). This ligament is often ossified in the cat. The osseous orbit is indented by the lacrimal gland (fossa glandulae lacrimalis), which lies under the zygomatic process or the orbital ligament respectively.

The frontal squama is separated from the temporal surface by the **temporal line** (linea temporalis), which extends caudally as the **external sagittal crest** (crista sagittalis externa) (Fig. 1-3, 4, 15 and 16). While it is a prominent structure in the dog, horse and ox, it is insignificant in the other domestic mammals. In horned ruminants the caudal end of the frontal squama carries the paired **cornual processes** (processus cornuales), which support the horn (Fig. 1-6).

The **nasal part** (pars nasalis) is the rostral extension of the frontal bone and is neighboured by the nasal bone rostrally and the lacrimal bone laterally. The **orbital part** (pars orbitalis) forms the major part of the medial wall of the orbital cavity, and is perforated ventrally by the **ethmoidal foramen** (foramen ethmoidale) (Fig. 1-18). In the horse the ethmoidal foramen opens on the border between the frontal and sphenoid bone. Medial to the base of the zygomatic process, the orbital part is indented by a shallow groove for the attachment of the dorsal oblique muscle of the eyeball.

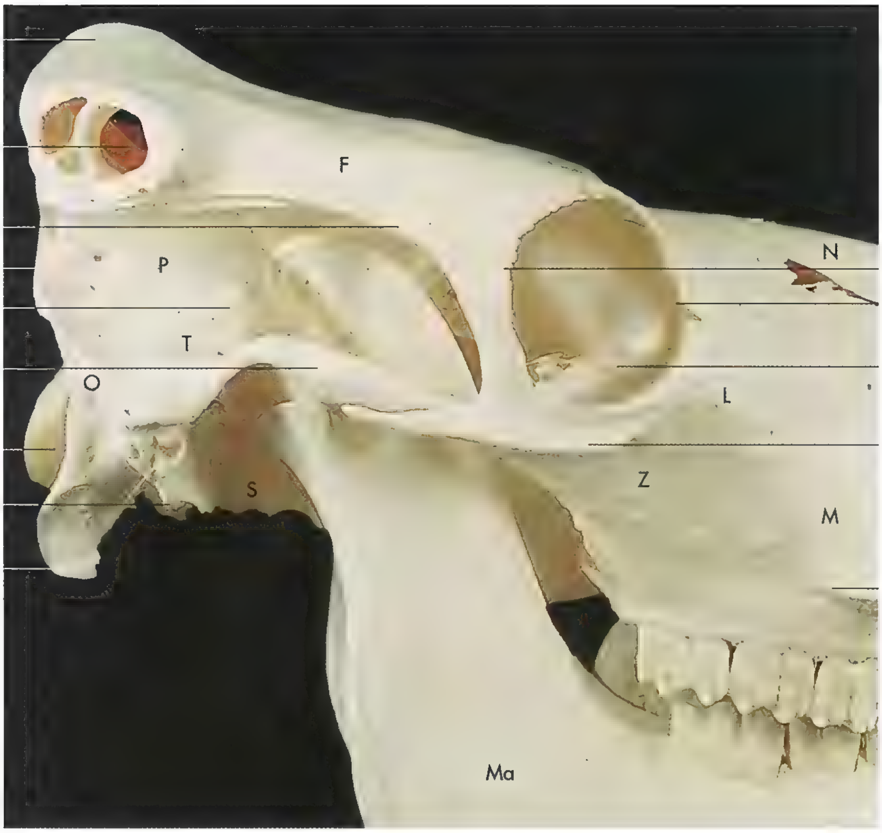

Fig. 1-15. Bones of the cranial part of a bovine skull (lateral aspect).

Fig. 1-16. Bones of the cranial part of a bovine skull (dorsal aspect).

Fig. 1-17. Bones of the cranial part of a bovine skull (medial aspect) of sagittal section.

Fig. 1-18. Bones of the cranial part of a bovine skull (ventral aspect).

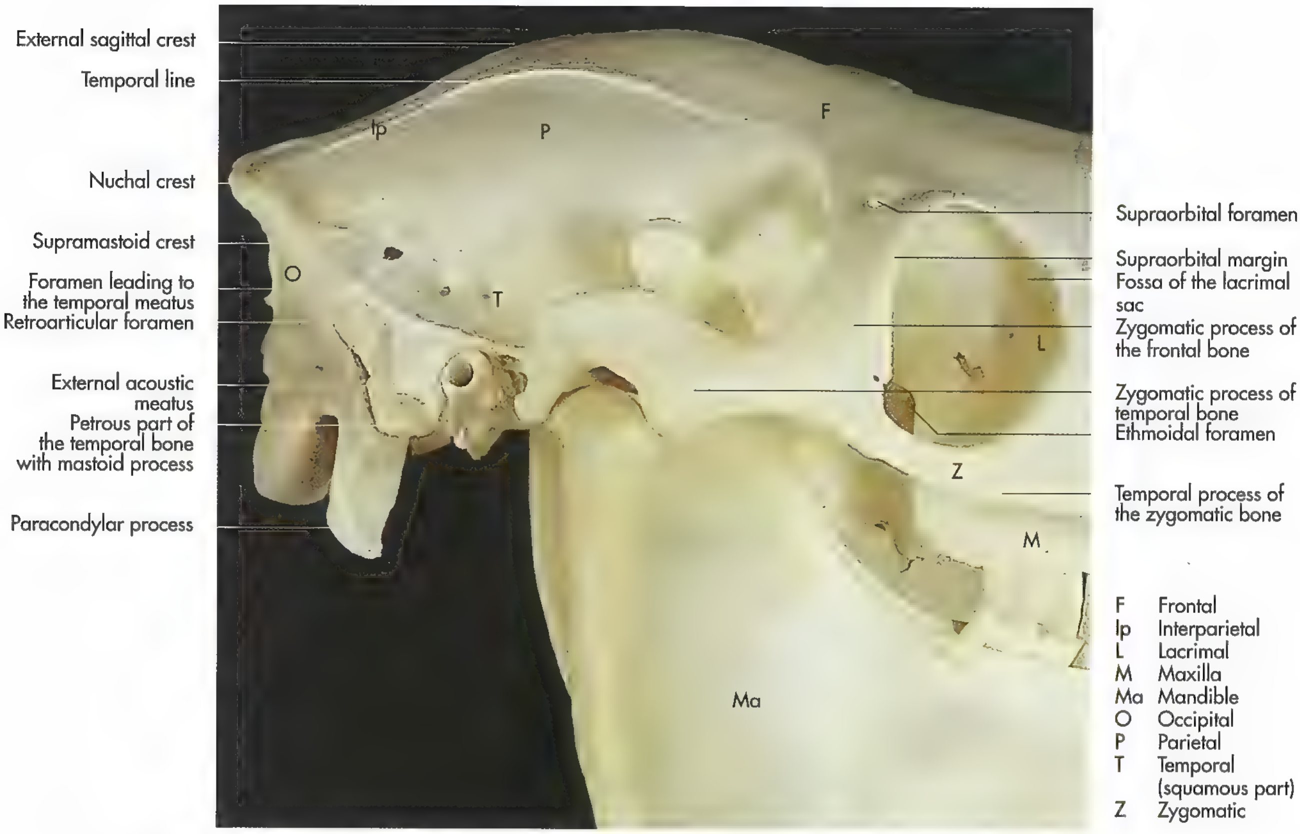

Fig. 1-19. Bones of the cranial part of an equine skull (lateral aspect).

Fig. 1-20. Bones of the cranial part of an equine skull (dorsal aspect).

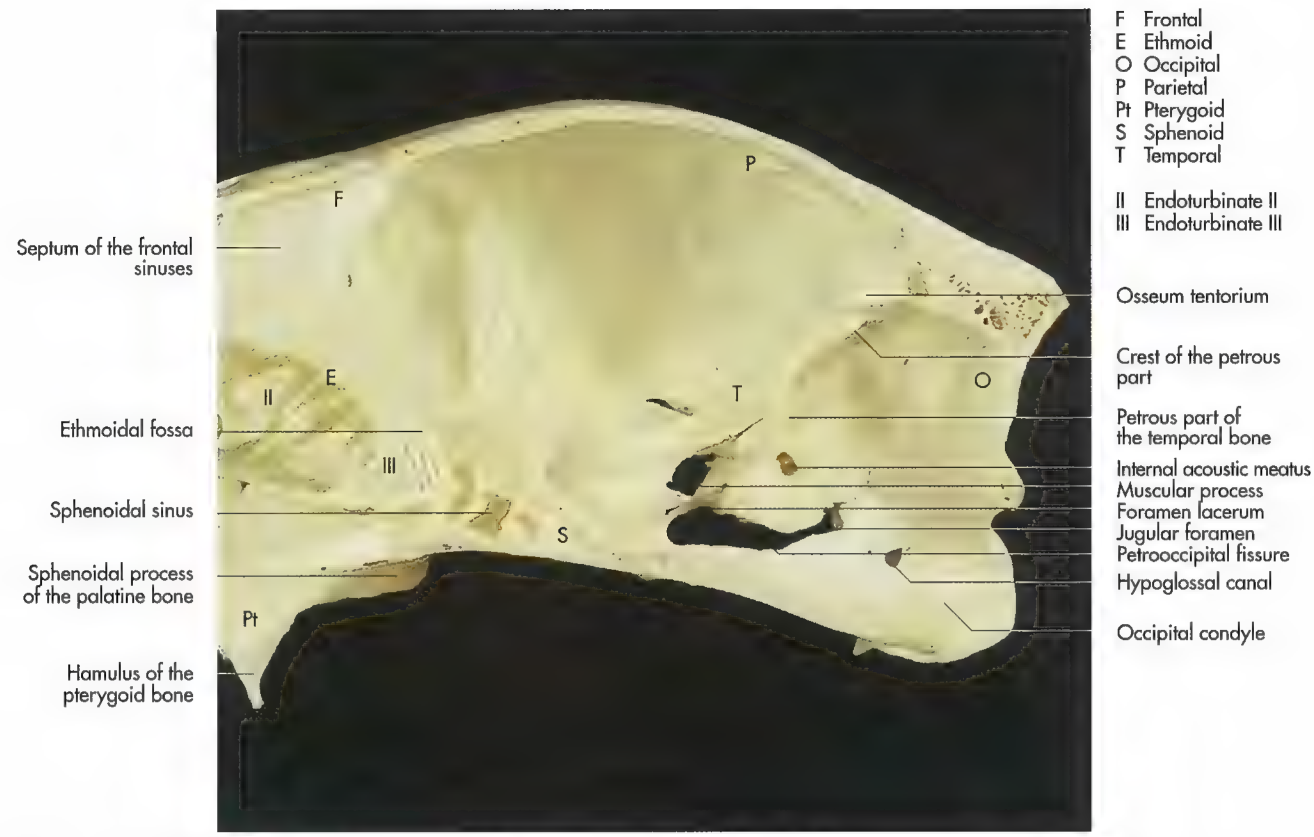

Fig. 1-21. Bones of the cranial part of an equine skull (medial aspect of sagittal section).

Fig. 1-22. Bones of the cranial part of an equine skull (ventral aspect).

F Frontal
E Ethmoid
I Incisive
M Maxilla
Mt Ventral nasal concha
N Nasal

I Endoturbinate I
II Endoturbinate II
III Endoturbinate III
IV Endoturbinate IV

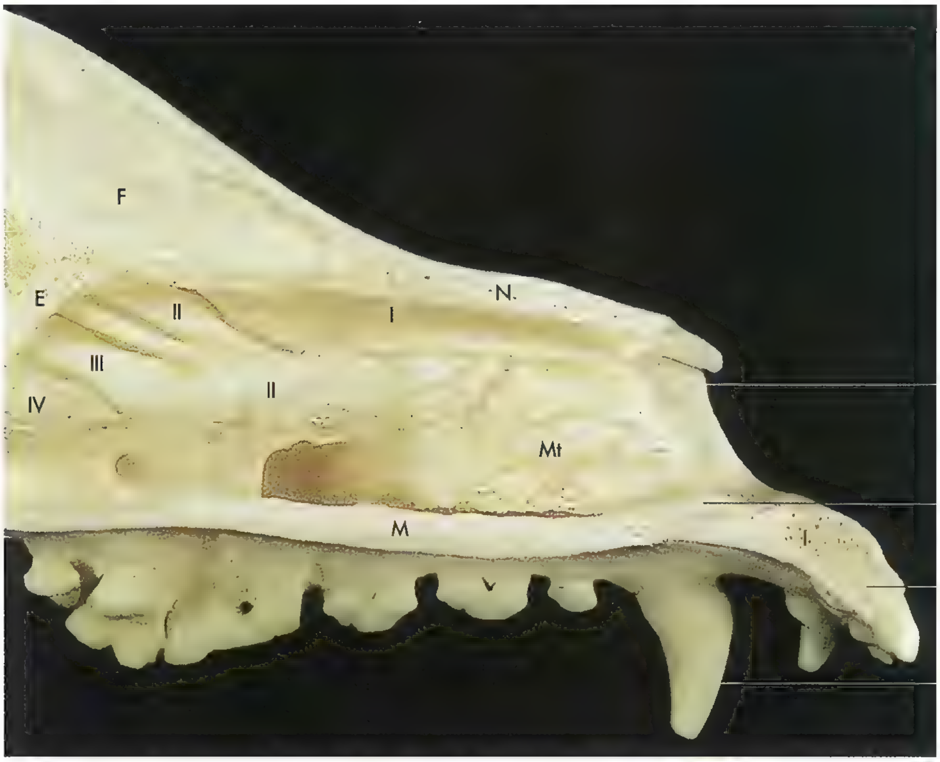

Fig. 1-23. Bones of the facial part of a canine skull (medial aspect of sagittal section).

Caudal to the orbital part is the small, concave temporal surface (facies temporalis). It forms the rostral part of the temporal fossa (fossa temporalis), which provides attachment for the temporal muscle (Fig. 1-20).

Parietal bone (os parietale)

The **parietal** is paired and forms most of the dorsolateral part of the cranial wall. It is bordered by the occipital bone caudally and the frontal bone rostrally. The external surface (facies externae) can be divided into a **parietal plane** (planum parietale) forming the dorsal wall of the neurocranium and a **temporal plane** (planum temporale) forming the lateral wall. The ox has an additional **nuchal plane** (planum nuchale), which contributes to the formation of the nuchal aspect of the skull.

The internal surface (facies interna) is characterised by vascular grooves and numerous depressions and ridges, which correspond to the sulci and gyri of the brain. In the horse and pig the internal surface is marked by the median **internal sagittal crest** (crista sagittalis interna), which is accompanied by the groove of the dorsal sagittal sinus (sulcus sinus sagittalis dorsalis). The caudal aspect of the internal surface of the parietal bone has a medial projection (processus tentoricus), which forms part of the **osseous tentorium cerebelli** (tentorium cerebelli osseum) in carnivores and horses (Fig. 1-5 and 21).

Interparietal bone (os interparietale)

The **interparietal** is centrally placed between the occipital bone and the parietal bone, with which it fuses during adult life, with the exception of the cat, where the sutures are still visible in the adult.

The processes tentoricus on the cerebral surface, fuses with the like-named processes of the parietal and occipital bones, forming the **osseous tentorium cerebelli** (tentorium cerebelli osseum) (Fig. 1-3, 4 and 21).

Ethmoid bone (os ethmoidale)

The **ethmoid bone** is situated deep to the walls of the orbit and contributes to the formation of the cranial and facial parts of the skull. The **external lamina** (lamina externa) of the tube-like ethmoid bone consists of the **roof plate** (lamina tectoria) cranially, the **floor plate** (lamina basalis) ventrally and the extremely thin paired **orbital plates** (laminae basales) to each side. The **cribriform plate** (lamina cribrosa) separates the ethmoid bone from the cranial cavity. A median sheet of bone, the **perpendicular plate** (lamina perpendicularis) divides the ethmoid into two tubes.

The paired **ethmoidal labyrinth** (labyrinthus ethmoidalis) protrudes from the dorsal and lateral walls of these tubes. The ethmoidal labyrinth is composed of delicate bony scrolls, the **ethmoturbinates** (ethmoturbinalia), with the **air-filled ethmoidal meatus** (meatus ethmoidales) between them (Fig. 1-23 and 24).

The **cribriform plate** (lamina cribrosa) is a sieve-like partition between the nasal and cranial cavities (Fig. 1-5, 13 and 14).

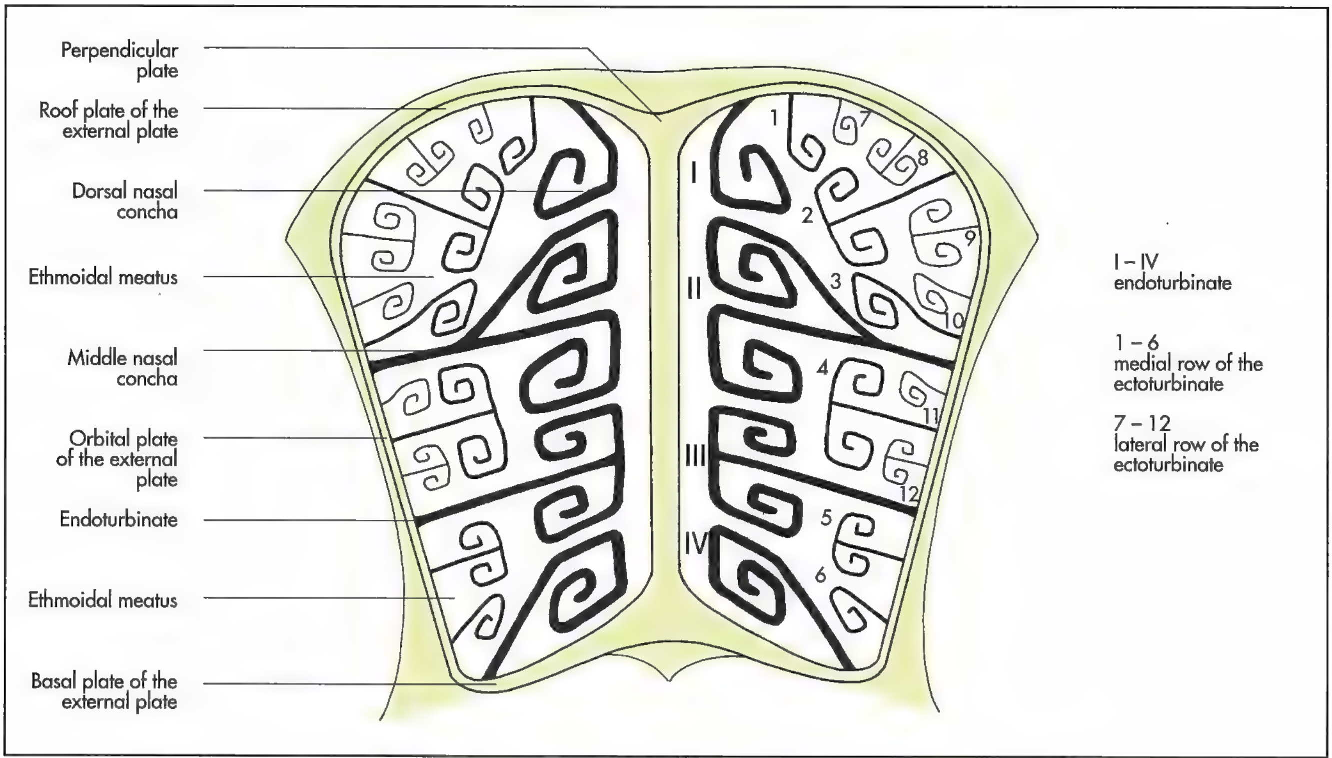

Fig. 1-24. Transverse section of the ethmoturbinates of the horse (schematic) (Nickel, Schummer and Seiferle, 1992).

The cribriform plate is perforated by numerous foramina through which the **olfactory nerve bundles** pass. These nerves pass from the olfactory cortices of the brain to the olfactory. The cerebral surface is divided into two parts by a median ridge, the crista galli, which is considered to be the intracranial continuation of the perpendicular plate. Each half is deeply concave forming the **ethmoidal fossae** (fossae ethmoidales), which enclose the olfactory bulbs (Fig. 1-13).

The **ethmoturbinates** (ethmoturbinalia) arise from the dorsal and lateral walls of the ethmoidal bone. They are arranged in two rows, except in the horse, where there are three (Fig. 1-24). Each ethmoturbinate possesses a basal leaf, which attaches to the walls of the ethmoid or the cribriform plate and a spiral leaf, which projects into the nasal cavity. The majority of the ethmoturbinates have a single scroll and turn ventrally, but some divide into a dorsal and a ventral scroll. Additional secondary turbinates can be found in all the domestic mammals, but are especially common in the dog.

The ethmoturbinates can be divided into long, deeply lying **endoturbinates** (endoturbinalia), which extend far into the nasal cavity, and shorter, more superficial **ectoturbinates** (ectoturbinalia). Ectoturbinates are normally arranged in a single row, with the exception of the horse, where they form a double row. The number of the turbinates on each side varies in the different species: Four endoturbinates and six ectoturbinates are found in the dog, seven endoturbinates and 20 ectoturbinates in the pig, four endoturbinates and 18 ectoturbinates in ruminants, six endoturbinates and 25 ectoturbinates in the horse.

The **first endoturbinate** (endoturbinale I) is the longest and most dorsal turbinate and extends far into the nasal cavity. It forms the osseous base of the **dorsal nasal conchae** (concha nasalis dorsalis) and attaches to the ethmoidal crest of the nasal bone.

The **second endoturbinate** (endoturbinale II) is second in the row next to the first and forms the bony part of the **middle nasal conchae** (concha nasalis media) (Fig. 1-24). The following turbinates diminish in size, with the exception of the dog, in which the second to fourth endoturbinates are especially well-developed. While the dorsal and middle nasal concha are formed by the endoturbinates, the **ventral nasal concha** (concha nasalis ventralis) is part of the **upper jaw** (maxilla).

The osseous structure of the **conchal bones** (ossa conchae) are described in the following summary:

- Endoturbinate I
  forms the dorsal nasal concha
  (concha nasalis dorsalis),
- Endoturbinate II
  forms the middle nasal concha
  (concha nasalis media) and
- Maxilla forms the ventral nasal concha
  (concha nasalis ventralis).

The endoturbinates protrude into the nasal cavities and form part of the nasal meatus. There are three nasal meatuses:

- **Dorsal nasal meatus** between the roof of the nasal cavity and the dorsal nasal concha,
- **Middle nasal meatus** between the two nasal conchae,
- **Ventral nasal meatus** between the ventral nasal conchae and the floor of the nasal cavity.

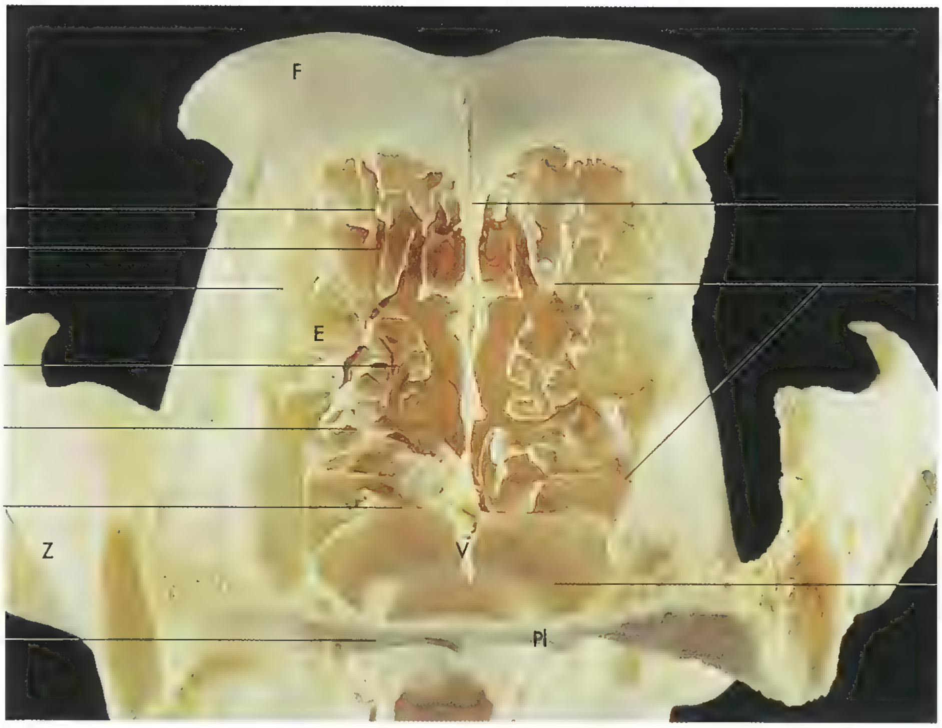

Fig. 1-25. Transverse section of the nasal cavity of a dog.

Skull, facial part (facies, viscerocranium)

The **bones of the facial part of the skull (ossa faciei)** form the walls of the nasal cavities, the floors of which form the osseous roof of the oral cavity. The floor and the lateral walls of the oral cavity are completed by the **lower jaw (mandible)** and supported by the **hyoid bone (os hyoideum)** ventrally.

The walls of the facial part of the skull are composed of the following segments in all domestic mammals:

- **The roof of the nasal cavity (dorsum nasi)** is formed by
  - Paired frontal bones (os frontale),
  - Paired nasal bones (os nasale).
- **The lateral walls of the nasal cavity** are formed by
  - Paired lacrimal bones (os lacrimale),
  - Paired zygomatic bones (os zygomaticum),
  - Paired upper jaw (maxilla),
  - Paired incisive bones (os incisivum).
- **The floor of the nasal cavity / the roof of the oral cavity** is formed by the
  - Paired palatine bones (os palatinum),
  - Paired upper jaw (maxilla),
  - Paired incisive bones (os incisivum),
  - Unpaired vomer.
- **The roof or lateral walls of the pharyngeal cavity** are formed by the
  - Paired pterygoid bones (os pterygoideum),
  - Parts of the unpaired vomer,
  - Paired palatine bones (os palatinum),
  - Paired sphenoid bones (os sphenoidale).

The **ethmoid bone** separates the nasal and cranial cavities. The dorsal and middle nasal conchae, formed by the first and second endoturbinate and the ventral nasal concha formed by the maxilla extend far into the nasal cavity. The nasal cavity is divided vertically into two equal halves by the median **nasal septum** (septum nasi) (Fig. 1-25).

Nasal bone (os nasale)

The **nasal bone** forms the roof of the nasal cavity and has a concave external surface (facies externa), except in some breeds of cat, pig and horse which have a convex nose. The **ethmoidal crest** (crista ethmoidalis) is on the internal surface (facies interna) and forms the attachment for the **dorsal nasal conchae** (endoturbinale I). The paired nasal bones present a blunt margin towards each other, articulating in a plane suture (sutura plana). The **rostral processes** (processus rostrales) form the apex of the nasal bone (Fig. 1-30 and 32). This ends centrally in the pig, sheep and horse, laterally in carnivores and has separate apices for each nasal bone in the ox. There is an additional process on the internal surface of the nasal bone of carnivores, which forms part of the nasal septum (processus septalis). The rostral process reaches beyond the bones located ventrally to it, thus forming the **nasoincisive notch** (incisura nasoincisiva) between the nasal and the incisive bone (Fig. 1-32).

Lacrimal bone (os lacrimale)

The **lacrimal bone** is a small bone situated near the medial canthus of the eye forming parts of the orbit and the lateral wall of the

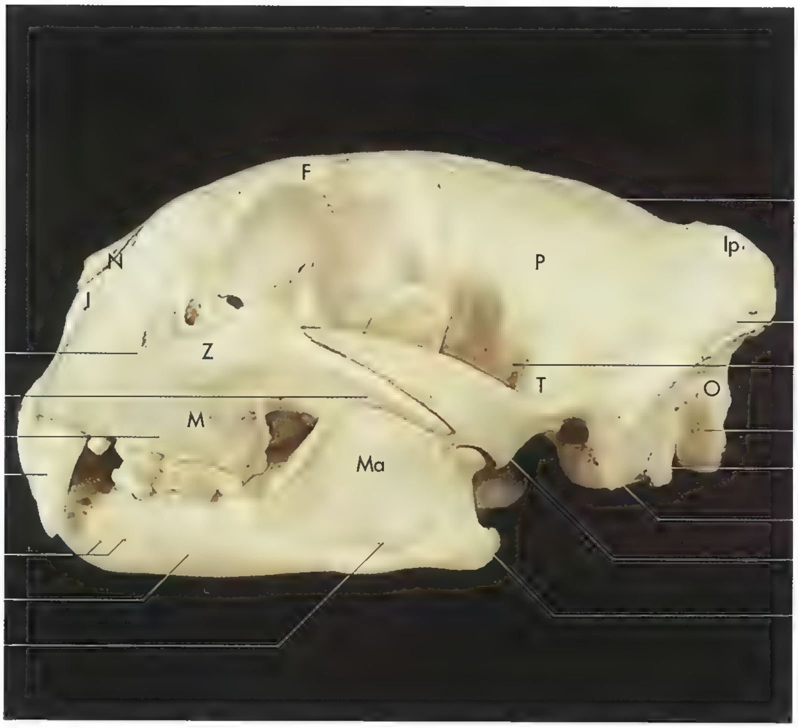

Fig. 1-26. Skull of a puma (lateral aspect).

face. It articulates with the frontal bone, the zygomatic bone and the maxilla in all domestic mammals and in ruminants and the horse, it also articulates with the nasal bone and in carnivores with the palatine bone. The **lateral surface** (facies lateralis) of the lacrimal bone can be divided into an **orbital part** (facies orbitalis) and a **facial part** (facies facialis), which are separated by the **supra-** and **infraorbital margins** (margo supraorbitalis, margo infraorbitalis) respectively. Near the margin of the orbital surface there is a funnel-shaped fossa, which is occupied by the dilated origin of the **nasolacrimal duct** (fossa sacci lacrimalis) (Fig. 1-19). Caudal to it is a depression for the origin of the ventral oblique muscle of the eye (fossa muscularis).

In ruminants the orbital part is large and bears the expanded thin-walled **lacrimal bulla** (bulla lacrimalis) ventrally, which contains an extension of the maxillary sinus (Fig. 1-15). The nasal surface (facies nasalis) forms the rostral limits of the frontal and maxillary sinuses and is crossed almost horizontally by the **nasolacrimal canal.**

Zygomatic bone (os zygomaticum)

The **zygomatic bone** lies ventrolateral to the lacrimal bone (Fig. 1-3, 4, 9 and 10) and forms parts of the bony orbit and the zygomatic arch (Fig. 1-8 and 10). The **zygomatic arch** (arcus zygomaticus) is formed by the union of the **temporal process** (processus temporalis) **of the zygomatic bone** and the **zygomatic process** (processus zygomaticum) of the **temporal bone** (Fig. 1-19). It extends towards the frontal bone, as the frontal process (processus frontalis) in all species except the horse. The frontal process articulates with the zygomatic process of the frontal bone in ruminants to form the **supraorbital margin** (margo supraorbitalis) (Fig. 1-19 and 46).

The supraorbital margin of the horse is formed by the zygomatic processes of the frontal and temporal bones. In carnivores and the pig the frontal process of the zygomatic bone is joined to the zygomatic process of the frontal bone by the **orbital ligament** (ligamentum orbitale), thus completing the orbital wall. The orbital ligament often ossifies in the cat. The orbital surface (facies orbitalis) joins the laterally situated facial surface (facies lateralis) in the infraorbital margin (margo infraorbitalis).

The lateral surface is marked by a longitudinal ridge, the **facial crest** (crista facialis), which is continuous rostrally with the like-named ridge on the maxilla. The facial crest is very prominent in the horse, S-shaped in ruminants and less distinct in carnivores and the pig (Fig. 1-38 and 57).

The zygomatic bone encloses air-filled cavities in some of the domestic species, thus participating in the system of the paranasal sinuses.

Maxilla

The paired maxilla provides the osseous basis for the major part of the facial part of the skull, it contributes to the formation of the lateral walls of the face, the nasal and oral cavities and the hard palate. It is the largest bone of the face and articulates with all of the facial bones (Fig. 1-27, 28 and 30). It can be divided into several portions:

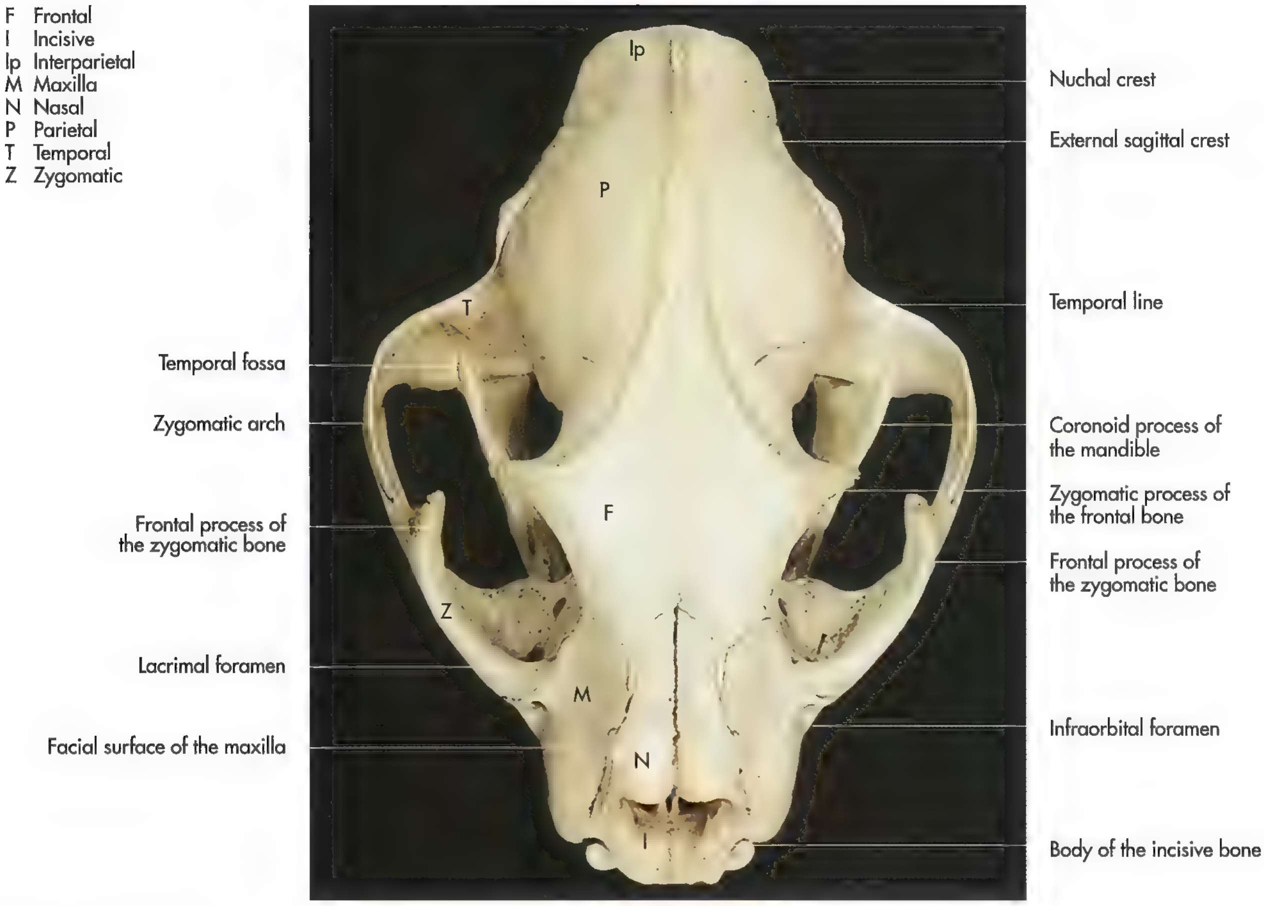

Fig. 1-27 Skull of a puma (dorsal aspect).

- Body (corpus maxillae) with
- External surface (facies facialis),
- Internal surface (facies nasalis),
- Pterygopalatine surface (facies pterygopalatina),
- Orbital surface (facies orbitalis) in the cat and horse
  - Alveolar process (processus alveolaris),
  - Palatine process (processus palatinus),
  - Frontal process (processus frontalis) in carnivores,
  - Zygomatic process (processus zygomaticus).

The **body of the maxilla** (corpus maxillae) encloses an air-filled cavity (except in carnivores), which constitutes the major part of the **maxillary sinus** (sinus maxillaris). This paranasal sinus extends also into the zygomatic and lacrimal bones. The pterygopalatine process of ruminants accomodates parts of the **palatine sinus** (sinus palatinus), which is continuous with the sinus cavity enclosed by the horizontal plate of the palatine bone.

The lateral wall of the maxillary body forms the **external surface of the face** (facies facialis) (Fig. 1-26 and 27). It is characterized by a horizontal ridge, the **facial crest** (crista facialis), which is especially prominent in the horse (Fig. 1-57), less distinct in ruminants and the pig and insignificant in carnivores. In ruminants the facial crest begins with the **facial tubercle** (tuber faciale), placed dorsal to the fourth cheek tooth and extends caudally as a rough line. There is a distinct facial crest in the pig, which ends at the **canine fossa** (fossa canina).

The prominent **infraorbital foramen** (foramen infraorbitale) opens dorsal and rostral to the rostral end of the facial crest. This is the external opening of the **infraorbital canal** (canalis infraorbitalis), which passes from the **maxillary foramen** (foramen maxillare) in the pterygopalatine fossa (fossa pterygopalatina) ventral to the orbit. The infraorbital artery, vein and nerve, which is a derivative of the facial nerve, pass through this canal.

The **infraorbital foramen** can be used as a palpable landmark for perineural anaesthesia of the infraorbital nerve. The infraorbital foramen is palpable and is situated on a imaginary line drawn from the nasoincisive notch to the rostral end of the facial crest in the horse, it is found 3 cm dorsal to the first maxillary cheek tooth in the ox and 1cm dorsal to the third cheek tooth in the dog. Prior to its exit, through the infraorbital foramen, the infraorbital canal divides into an additional canal (canalis alveolaris) through which the nerves and blood vessels of the incisors pass.

The nasal surface has a distinct ridge, the **conchal crest** (crista conchalis) where the **ventral nasal concha** (concha nasalis ventralis) attaches (Fig. 1-29 to 32). The spiral part of the ventral nasal concha turns dorsally towards the middle nasal meatus in the horse and encloses in its caudal part, a

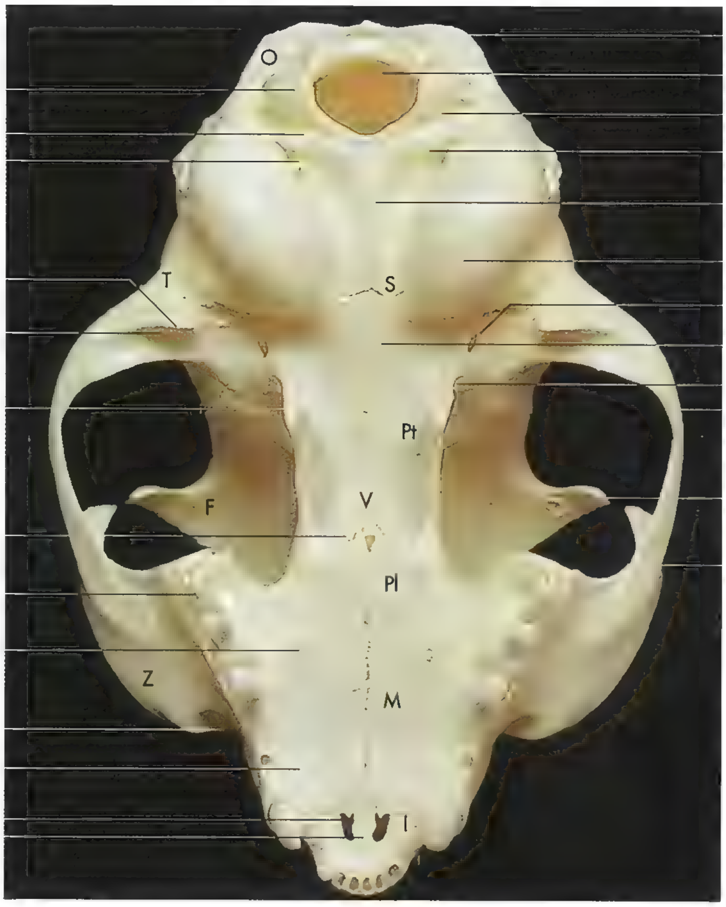

Fig. 1-28. Skull of a cat (ventral aspect).

tunnel-shaped paranasal **sinus** (sinus conchae nasalis ventralis), which communicates with the rostral part of the **maxillary sinus** (sinus maxillaris rostralis) and thus with the nasal cavity. The ventral nasal concha of the other domestic mammals divides into a dorsal spiral leaf towards the middle nasal meatus and a ventral one towards the ventral nasal meatus. The bony part of the **lacrimal canal** (canalis lacrimalis) opens on the nasal surface of the maxillary bone in the **lacrimal foramen** (foramen lacrimale), which is situated dorsal to the facial crest in horses and ventral to it in the other domestic mammals.

The **pterygopalatine surface** (facies pterygopalatina) forms the caudal part of the maxilla extending to the **maxillary tubercle** (tuber maxillae) (Fig. 1-57) and demarcates the medially located pterygopalatine fossa, in which the **maxillary** (foramen maxillare), the **sphenopalatine** (foramen sphenopalatinum) and the **caudal palatine** foramina (foramen palatinum caudale) open (Fig. 1-47 and 52). The **alveolar process** (processus alveolaris) encloses the cavities for the teeth, the **dental alveoli** (alveoli dentales) and on its free border, the **alveolar margin** (margo alveolaris). The alveoli are separated by transverse **interalveolar septa** (septa interalveolaria). The **interalveolar margin** (margo interalveolaris) extends between the canine and first cheek tooth (Fig. 1-38). The lower facial surface of the maxilla presents smooth elevations (juga alveolaria) caused by the roots of the teeth.

The **palatine process** (processus palatinus) is a transverse plate of bone which arises from the alveolar process and meets its contralateral pair in the **median palatine suture** (sutura palatina mediana) (Fig. 1-28 and 33). It forms the osseous hard palate together with the palatine bone, with which it articulates caudally. Rostrally it articulates with parts of the incisive bone in the formation of the bony **palatine fissure** (fissura palatina) (Fig. 1-33). These paired horizontal plates of bone, together with the incisive bone, form the floor of the nasal cavity, which constitutes the roof of the oral cavity. The nasal surface of the palatine process forms the **nasal crest** (crista nasalis) to which the vomer attaches (Fig. 1-31). The oral surface is perforated by the **major palatine foramen** (foramen palatinum majus), the location of which varies among the different domestic species (Fig. 1-33). The palatine process encloses parts of the **palatine sinus** (sinus palatinus) (Fig. 1-32).

Incisive bone (os incisivum)

The paired **incisive bones** each consist of the **body** (corpus ossis incisivi) (Fig. 1-27, 28 and 32), **nasal** (processus nasalis) (Fig. 1-32), **palatine** (proccessus palatinus) and **alveolar processes** (processus alveolaris) (Fig. 1-33). The incisive bones form the rostral portion of the facial part of the skull and form part of the opening to the nasal cavity and the roof of the hard palate.

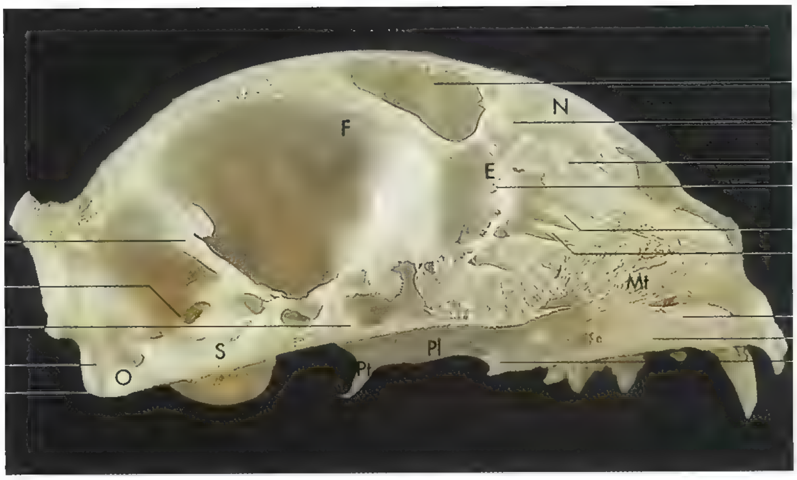

Fig. 1-29. Skull of a cat (medial aspect of sagittal section).

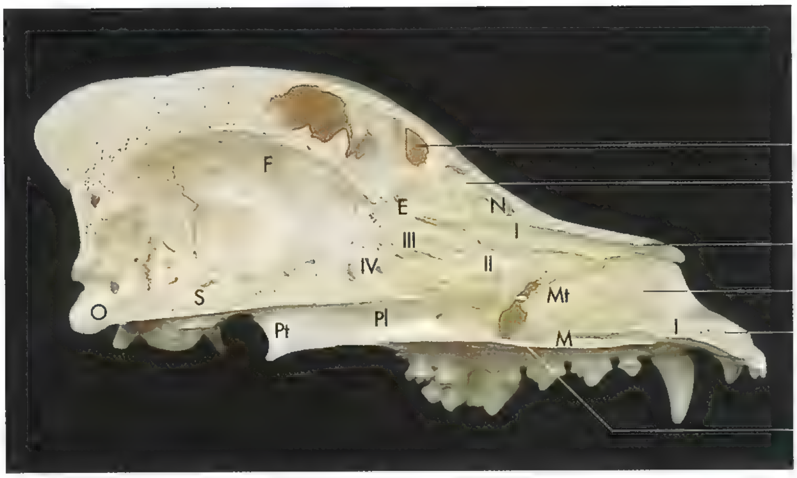

Fig. 1-30. Skull of a dog (medial aspect of sagittal section).

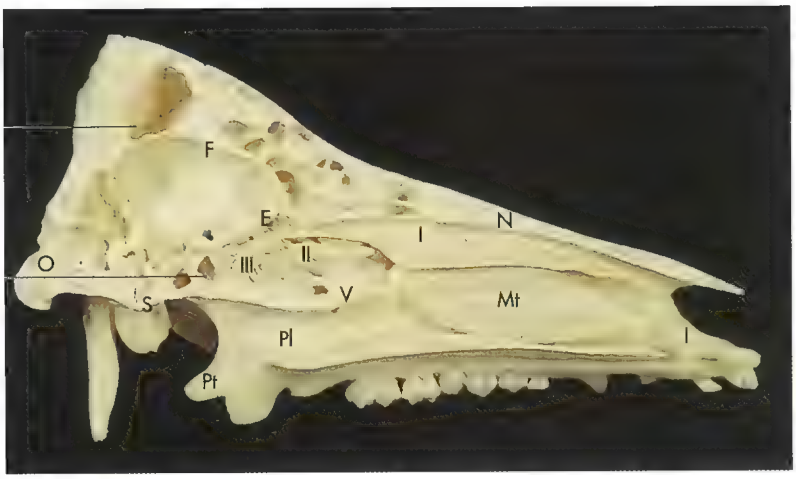

Fig. 1-31. Skull of a pig (medial aspect of sagittal section).

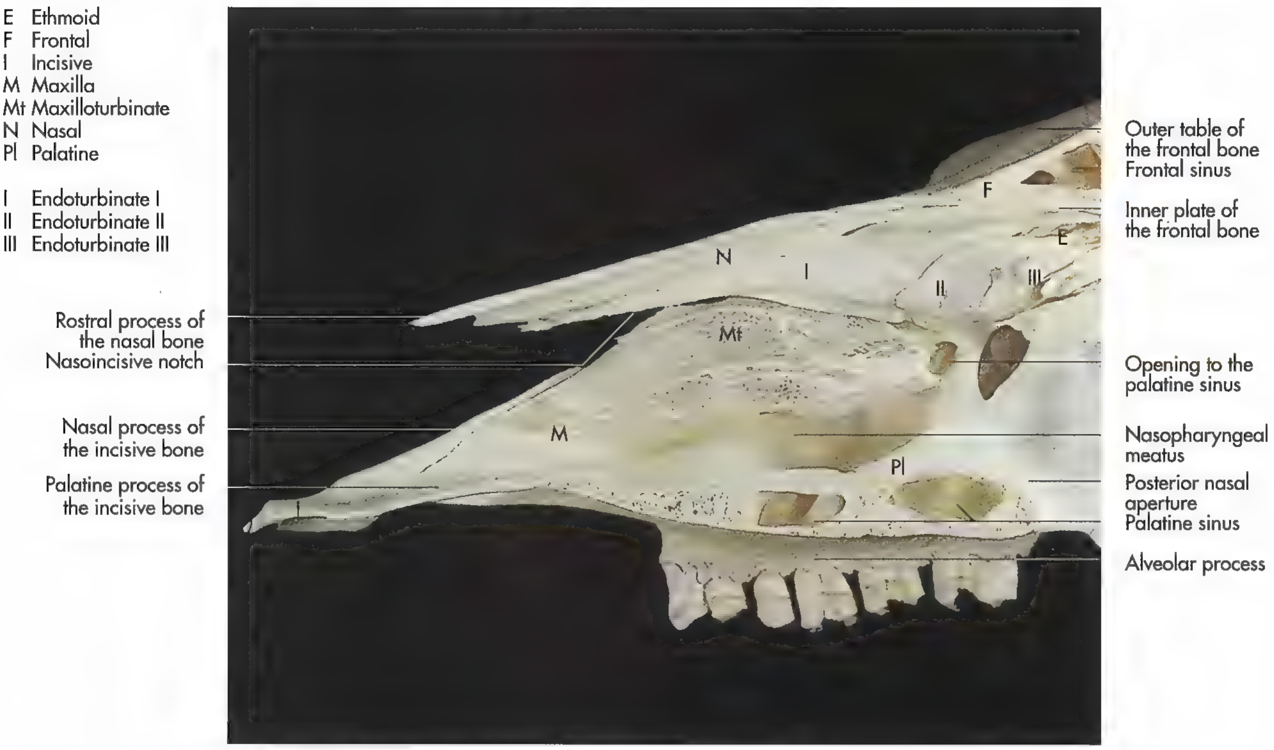

Fig. 1-32. Bones of the facial part of an equine skull (medial aspect of sagittal section).

The body of the incisive bone presents two surfaces, the concave **palatine surface** (facies palatina) and the convex **labial surface** (facies labialis). It extends rostrally to form the alveolar process. The **alveolar process** form conical sockets, the **dental alveoli** for the three incisor teeth of each side. Since there are neither upper incisor teeth, nor a canine tooth in ruminants, the dental alveoli for these teeth are lacking in these species. The alveolar process of the incisive bone joins the maxilla caudally forming the **interalveolar margin,** which is relatively long in horses, but short in pigs and carnivores. The palatine process of the incisive bone meets its contralateral pair in the mid-line, they are either firmly fused in the interincisive suture (carnivores and pig) or leaving a narrow cleft, the interincisive fissure (pig and ruminants).

In humans the incisive bone (also called Goethe's bone) remains separate until four years of age, after which it is firmly fused with the maxilla.

Palatine bone (os palatinum)

The paired **palatine bones** are located between the maxilla, the sphenoid and the pterygoid bones. They are divided into a **horizontal plate** (lamina horizontalis) which forms part of the hard palate (Fig. 1-25 and 33) and a **perpendicular plate** (lamina perpendicularis), which forms part of the lateral and dorsal walls of the **nasopharyngeal meatus** (meatus nasopharyngeus) and the **choanae,** the openings, which lead from the nasal cavities to the nasopharynx (Fig. 1-32).

The **caudal border** (margo liber) of the horizontal plate is free and directed towards the nasopharyngeal meatus. It forms the caudal part of the hard palate to which the soft palate attaches. The nasal surface of the horizontal plate, adjacent to the median palatine suture, is marked by the **nasal crest** (crista nasalis), which ends caudally in the mostly unpaired **nasal spine** (spina nasalis caudalis). The horizontal plate encloses part of the **palatine sinus** (sinus palatinus), which also extends into the palatine process of the maxilla, in the ox. The **palatine canal** (canalis palatinus) runs through the horizontal plate and allows the passage of the major palatine artery, vein and nerve. The perpendicular plate joins the horizontal plate at a right angle and extends to the sphenoid and pterygoid bones caudally and the walls of the orbit rostrally (Fig. 1-33). It extends medially to form the **sphenoethmoidal plate** (lamina sphenoethmoidalis), which articulates with the base of the ethmoid and the vomer. Its free margin completes the border of the choanae laterally. In the horse the perpendicular plate encloses the palatine sinus.

Vomer

The **vomer** is an unpaired bone, that extends from the choanal region into the nasal cavity, where it attaches to the median nasal crest (crista nasalis) on the floor of the nasal cavity (Fig. 1-31). Its basal part extends to the nasal crest of the horizontal plate of the palatine bone in carnivores, whereas in ruminants, it joins the palatine process of the maxilla. The two lateral plates extend from each side of the base dorsally, thus forming a narrow groove, the **septal sulcus** (sulcus septalis), which surrounds the nasal septum.

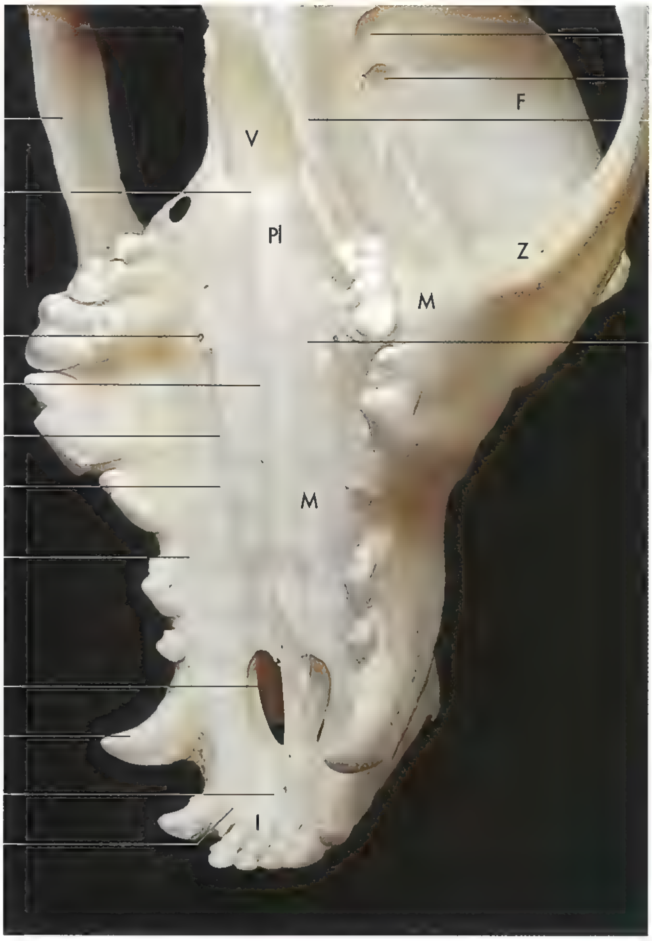

Fig. 1-33. Bones of the facial part of a canine skull (ventrolateral aspect).

Pterygoid bone (os pterygoideum)

The **paired pterygoid bone** is a thin bony plate, bordered by the sphenoid bone and the horizontal plate of the palatine bone. It forms part of the dorsal and lateral walls of the nasopharyngeal cavity. Its free margin forms a small hook-shaped process, the **pterygoid hamulus** (hamulus pterygoideus), which projects beyond the margin of the choanae, it is well-developed in the horse (Fig. 1-28 and 63).

Mandible (mandibula)

The two halves of the **mandible** develop in the cranial mesoderm of the first branchial arch and articulate firmly at the **mental angle** (angulus mentalis) forming the median **mandibular synchondrosis** (synchondrosis intermandibularis) rostrally. This fibrous union is normally completed during the first year post partum in the pig and the horse but may occur later in life, or remains bipartate in carnivores and ruminants. Each half can be divided into (Fig. 1-34 to 37):

- Body of the mandible (corpus mandibulae), supporting the teeth and
- Mandibular ramus (ramus mandibulae).

From the synchondrosis the two halves diverge, enclosing the **mandibular space** (spatium mandibulae) between them.

The body of the mandible can be subdivided into a **rostral part** (pars incisiva), that contains the incisor teeth and a **caudal part** (pars molaris), that contains the cheek teeth. The incisive part consists of a horizontal plate with a convex surface towards the lips (facies labialis) and a concave surface towards the tongue (facies lingualis), which meet at the **alveolar border** (arcus alveolaris). The alveolar border is indented by six conical cavities for the roots of the incisor teeth (alveoli dentales). The dental alveolus for the canine tooth is situated directly caudal to it in carnivores and ruminants and some space apart in the horse and the pig. The molar part has a lateral **buccal surface** (facies buccalis) and a medial **lingual surface** (facies lingualis), which are separated by the **ventral margin** (margo ventralis). The caudal part of the **dorsal border** (margo alveolaris) forms the sockets, which contain the roots of the cheek teeth. There are three cheek teeth in the cat,

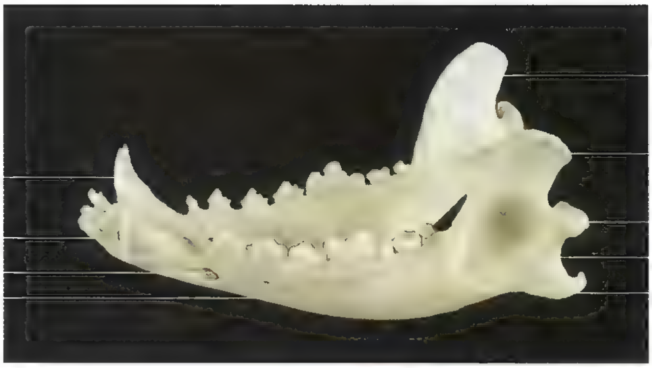

Fig. 1-34. Mandible of the dog.

Fig. 1-35. Mandible of a pig.

Fig. 1-36. Mandible of an ox.

Fig. 1-37. Mandible of a stallion.

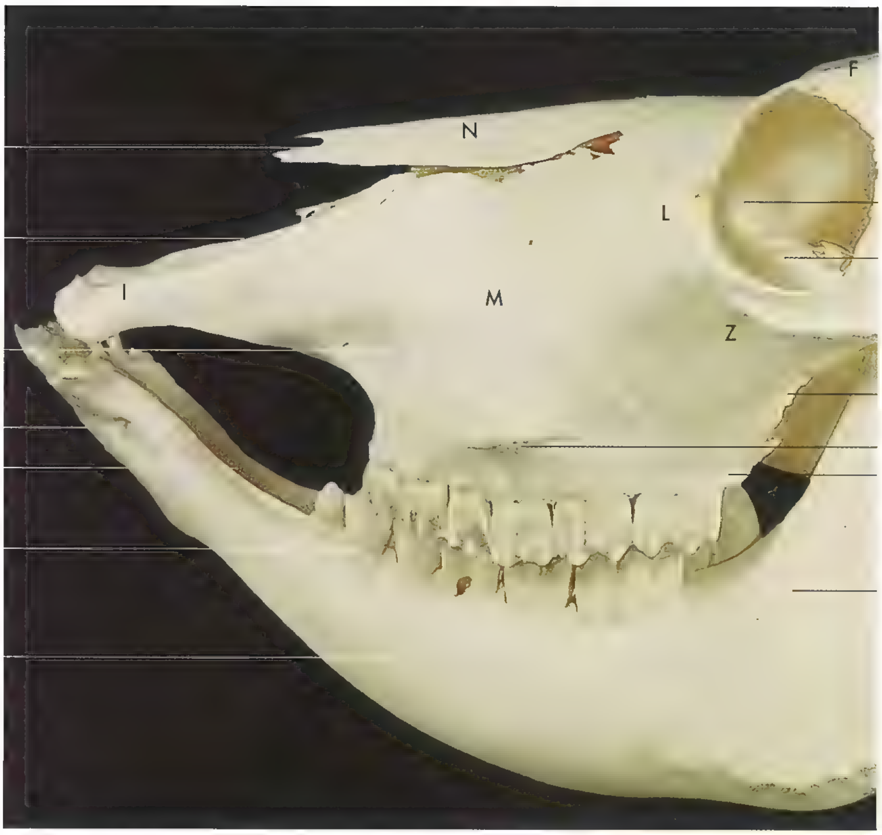

Fig. 1-38. Bones of the facial part of a bovine skull (lateral aspect).

seven in the dog and the pig, six in ruminants and six or seven in the horse.

The tooth-free rostral part of the dorsal margin between the canine and the first cheek tooth is termed the **interalveolar margin** (margo interalveolaris) or **diastema,** which is longest in horses and ruminants.

The body of the mandible contains the **mandibular canal** (canalis mandibularis), through which the mandibular artery and vein and the mandibular alveolar nerve (n. alveolaris mandibularis) pass. The mandibular canal has its caudal opening in the **mandibular foramen** (foramen mandibulae) on the medial surface of the mandible, it passes rostrally, ventral to the dental alveoli and ends in the **mental foramen** (foramen mentale) on the lateral surface of the **interalveolar margin** (margo interalveolaris). The mental foramen consists of a single opening in ruminants and the horse and of two or three openings in carnivores and up to five openings in the pig. The mandibular canal continues rostrally to the dental alveoli of the incisor and canine teeth as the alveolar canal (canalis alveolaris). The ventral border of the mandibular body is marked by a smooth indentation, the **facial notch** (incisura vasorum facialium), where the facial vessels and the parotid duct curve around the bone. In the horse the pulse is commonly palpated at this site (Fig. 1-37).

The mental and mandibular foramen can be used as landmarks for perineural anaesthesia:

- **Mental foramen** (foramen mentale):
  - Horse: On the lateral surface of the interalveolar margin 1 cm below the dorsal border at the level of the rostral end of the intermandibular space.
  - Ox: On the lateral surface 1 cm ventral and caudal to the canine.
  - Dog: In the middle of the lateral surface ventral to the first cheek tooth.
- **Mandibular foramen** (foramen mandibulae):
  - Horse and ox: On the medial surface on the center of an imaginary line, drawn from the condylar process to the facial notch (incisura vasorum facialium).
  - Dog: On the medial surface 2 cm caudal to last cheek tooth.

The **ramus of the mandible** (ramus mandibulae) is a vertical bone plate, which extends from the mandibular body towards the zygomatic arch (Fig. 1-34 to 37). Its lateral surface is characterized by the **masseteric fossa** (fossa masseterica), which is the site of attachment of the **masseter muscle** (m. masseter), its medial surface the **pterygoid fossa** (fossa pterygoidea) which is the site of attachment of the medial pterygoid muscle (m. pterygoideus medialis). The caudoventral part of the mandibular ramus forms the **angle of the mandible** (angulus mandibulae), which extends a hooked process in carnivores, the **angular process** (processus angularis).

Fig. 1-39. Hyoid bone of a cat.

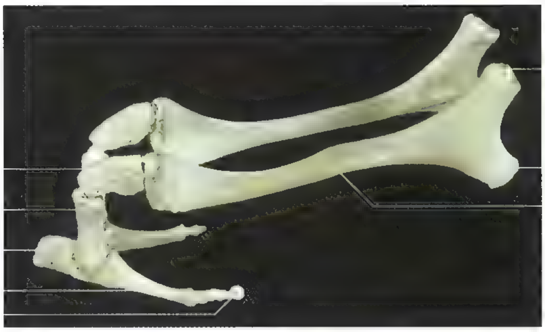

Fig. 1-40. Hyoid bone of an ox.

Fig. 1-41. Hyoid bone of a horse.

The free end of the mandibular ramus consists of the **condylar process** (processus condylaris) and the transversely elongated **mandibular head** (caput mandibulae) for the formation of the temporomandibular joint caudally. Rostrally it extends to form the long **coronoid process** (processus coronoideus), where the **temporal muscle** (m. temporalis) inserts. These two processes are separated by the **mandibular notch** (incisura mandibulae) (Fig. 1-34 to 37).

Hyoid bone, hyoid apparatus (os hyoideum, apparatus hyoideus)

The **hyoid bone** develops from parts of the second and third branchial arches; its separate cartilagenous components ossify early in life and unite forming firm synchondroses. The hyoid bones are situated between the rami of the mandible at the base of the tongue and acts as a **suspensory mechanism for the tongue and larynx.** It can be divided into two parts. The first part connects to the tongue and larynx and is regarded as the hyoid apparatus, equivalent to that of man. The second is directed dorsally, articulating with the temporal bone and is termed the suspensory apparatus.

The major part of hyoid corresponds to that of man and consists of three components (Fig. 1-39 to 41):

- Basihyoid or body (corpus ossis hyoidei, basihyoideum),
- Thyrohyoid (thyreohyoideum) and
- Ceratohyoid (ceratohyoideum).

The **basihyoid** is a short transverse unpaired bone lying in the musculature of the base of the tongue. Its rostral border carries medially the **lingual process** (processus lingualis), which is long in the horse and shorter in ruminants.

Tab. 1-1. Openings of the skull and transmitted structures.

Openings	Bones	Transmitted structures	Particulars
Hypoglossal canal	Occipital	Hypoglossus nerve (XII) Condylar vein and artery	Often double in the ox; Foramen in the horse
Optic canal	Presphenoid	Optic nerve (II)	Lies above the sphenoidal sinus
Orbital fissure	Presphenoid	Ophthalmic nerve (V_1) III., IV. and VI. cranial nerve	In carnivores and in the horse
Foramen rotundum	Presphenoid	Maxillary nerve (V_2)	Foramen orbitorotundum in ruminants and in the pig
Caudal alar foramen	Basisphenoid	Maxillary artery	
Rostral alar foramen	Basisphenoid	Maxillary artery	In the dog also the maxillary nerve (V_2)
Small alar foramen	Basisphenoid	Rostral deep temporal artery	Only in the horse
Foramen lacerum	Basioccipital, Temporal, Basisphenoid	Internal carotid artery, Mandibular nerve (V_3) Middle meningeal artery	In the horse and pig
Jugular foramen	Basioccipital Temporal	IX., X. and XI. Cranial nerve, Dog: Internal carotid artery	Foramen lacerum as the caudal part
Oval foramen	Basisphenoid	Mandibular nerve (V_3)	In the horse the oval notch lies in the foramen lacerum
Carotid canal	Basisphenoid	Internal carotid artery (excl dog) Internal carotid nerve	In the horse carotid notch and foramen lacerum
Spinous foramen	Basisphenoid	Trochlear nerve (IV) MIddle meningeal artery	In the horse spinous notch and foramen lacerum
Supraorbital foramen	Frontal	Frontal nerve (V_1), Frontal vein and artery	Lacking in carnivores

The **thyrohyoid** projects caudally from the basihyoid, with which it is firmly fused in ruminants and horses, towards the thyroid cartilage of the larynx with which it forms a movable joint. The **ceratohyoid** articulates with the basihyoid and the thyrohyoid caudally and the epihyoid proximally, thus connecting the hyoid with the suspensory apparatus.

The suspensory apparatus joins the hyoid bones to the skull in a species specific way: In ruminants and the horse the hyoid articulates with the **styloid process** (processus styloideus) of the tympanic part of the temporal bone, in carnivores with the **mastoid process** (processus mastoideus) of the petrous temporal bone and in the pig with the **nuchal process** (processus nuchalis) of the squamous temporal bone.

It consists of three parts:

- The proximal part or tympanohyoid (tympanohyoideum),
- The middle part or stylohyoid (stylohyoideum) and
- The distal part or epihyoid (epihyoideum).

The **tympanohyoid** is a short cartilagenous bar in most animals and composed of fibrous tissue in carnivores. It is a continuation of the proximal end of the stylohyoid and is fused to the temporal bone. The **stylohyoid** is a laterally flattened cylinder in ruminants and the horse, the distal part remains cartilagenous in pigs and carnivores. The **epihyoid** is interposed between the stylohyoid and the ceratohyoid. It is cylindrical in carnivores, fused with the stylohyoid in horses and replaced by the **epihyoid ligament** (ligamentum epihyoideum) in pigs.

Paranasal sinuses (sinus paranasales)

The **paranasal sinuses** are air-filled cavities between the external and internal lamina of the bones of the skull, which are connected to the nasal cavity (Fig. 1-29 to 32, 51 to 54, 64 and 65). Since the paranasal sinuses vary greatly in the different domestic mammals, they are describes separately for the different species.

Tab. 1-1. Openings of the skull and transmitted structures (continued).

Openings	Bones	Transmitted structures	Particulars
Ethmoidal foramen	Frontal	Ethmoidal nerve (V_1) Ethmoidal vein and artery	
Petrooccipital fissure	Temporal/ Occipital	Greater petrosal nerve (VII) Chorda tympani (VII)	
Retroarticular foramen	Squamous temporal	Emissary veins for the temporal sinus	
Facial area	Petrous part	Facial nerve (VII)	Internal acoustic meatus
Cochlear area	Temporal	Cochlear nerve ((VIII)	Internal acoustic meatus
Dorsal vestibular area	Temporal	Vestibular nerve (VIII)	Internal acoustic meatus
Ventral vestibular area	Temporal	Vestibular nerve (VIII)	Internal acoustic meatus
Stylomastoid foramen	Petrous part/ Tympanic part	Facial neve (VII)	
Maxillary foramen	Maxilla	Maxillary nerve (V_2) , vein and artery	Pterygopalatine fossa
Caudal palatine foramen	Maxilla	Greater palatine nerve (V_2), vein and artery	Pterygopalatine fossa
Sphenopalatine foramen	Maxilla	Caudal nasal nerve (V_2), Sphenopalatine vein and artery	Pterygopalatine fossa
Infraorbital foramen	Maxilla	Infraorbital nerve (V_2), vein and artery	
Interincisive canal	Incisive	Greater palatine artery	
Mandibular foramen	Mandible	Mandibular nerve (V_3), vein and artery	
Mental foramen	Mandible	Mental nerve (V_3), vein and artery	
Major palatine foramen	Palatine	Greater palatine nerve (V_2) and artery	Greater palatine vein only in small ruminants

- Maxillary sinus (sinus maxillaris),
- Frontal sinus (sinus frontalis),
- Palatine sinus (sinus palatinus),
- Sphenoidal sinus (sinus sphenoidalis),
- Lacrimal sinus (sinus lacrimalis) in pigs and ruminants,
- Dorsal conchal sinus (sinus conchae dorsalis) and ventral conchal sinus (sinus conchae ventralis) in the pig, ruminants and the horse and
- Cellulae ethmoidales in the pig and ruminants.

The skull as a whole

The skull of carnivores

There are many variations in the shape of the skull, not only between the different carnivore species, but also amongst the different breeds, especially in the dog. Based on the form of the skull, the canine breeds can be grouped in **dolichocephalic** (meaning long, narrow-headed), **brachycephalic** (meaning short, wide-headed) and **mesocephalic** (meaning a head of medium proportions) breeds. Doliochocephalic breeds have an elongated facial skeleton and a narrow cranial part with a distinct **external sagittal crest** (crista sagittalis externa) for the attachment of the temporal muscle (Fig. 1-42). The frontal and nasal part is flatly concave and the zygomatic arches protrude less laterally than in the other groups. Some breed examples are: Border Collie, Irish Wolfhound, Greyhounds.

In brachiocephalic breeds the cranial part of the skull is relatively large compared to the facial part, which is shortened and broadened. The external sagittal crest is reduced or missing altogether. In some breeds the fontanelles remain open throughout life. This group includes Pekingeses, Pugs, Pomeranian and some Spaniels. In some brachycephalic breeds the lower jaw protrudes rostral to the upper jaw, producing the condition known as **prognathism of the mandible** (Fig. 1-45).

Fig. 1-42. Skull and mandible of a five year old Husky (lateral aspect).

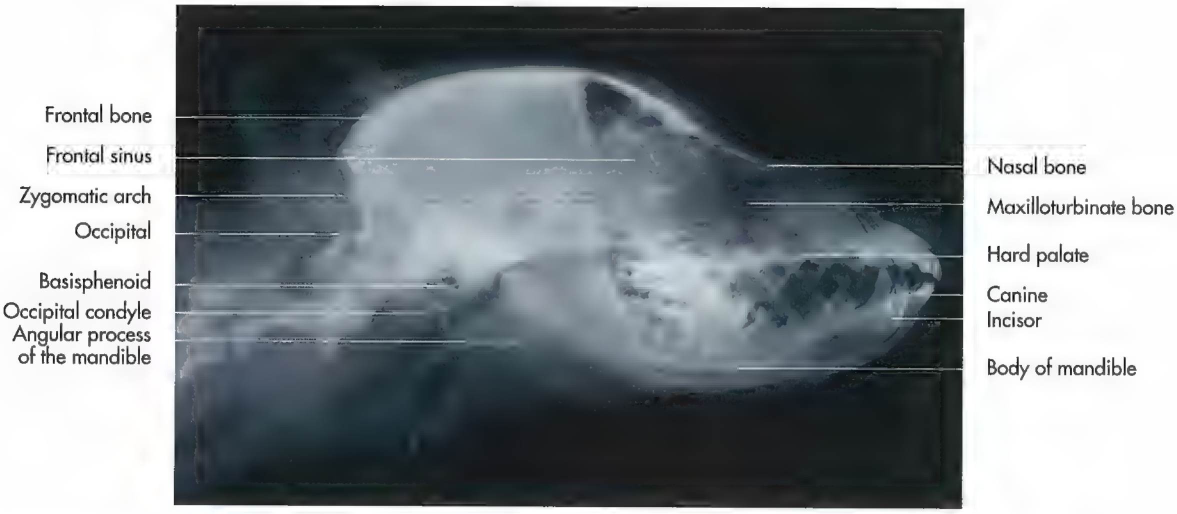

Fig. 1-43. Radiograph of a canine skull (laterolateral projection) (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

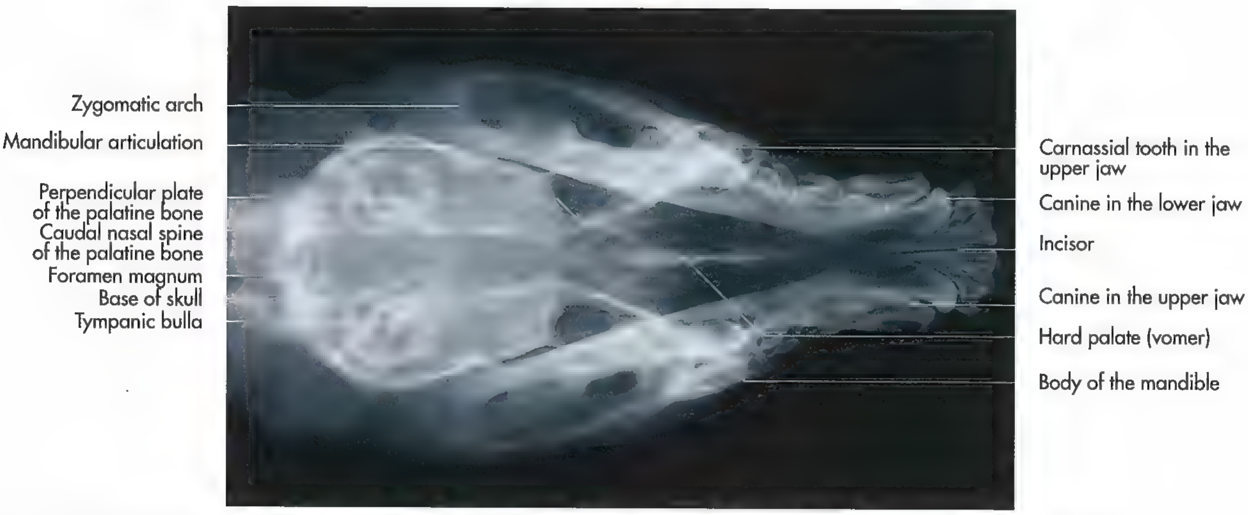

Fig. 1-44. Radiograph of a canine skull (ventrodorsal projection) (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

Fig. 1-45. Canine skull with prognathism of the mandible (lateral aspect).

In mesocephalic breeds, such as Beagles or Dachshounds, the facial and cranial part of the skull are well proportioned, resulting in an average conformation between the two other groups.

In spite of these breed-specific variations, which are complemented by age and gender specific characteristics, the basic architecture of the canine skull remains the same. It is generally stated that the skull of the dog is relatively large, which is thought to be of life-saving importance in predatory animals, since the skull hosts the sense organs (e.g. sight, hearing and smell) and the brain. Therefore this type of skull is characterised by a well-developed facial part, dominant orbital cavities with incomplete, fibrous orbits, distinct temporal fossae and large tympanic bullae.

Compared to the mesocephalic dog the face of the cat is shorter, the orbital cavities larger and positioned more frontally, thus enlarging the field of binocular vision (Fig 1-26 and 27).

The nuchal surface of the skull of carnivores is formed by the squamous and lateral parts of the occipital bone and by the narrow caudal part of the petrous temporal bone in the dog. It is separated from the roof of the skull by the **external occipital protuberance** (protuberantia occipitalis externa) and the **nuchal crest** (crista nuchae), both of which provide attachment to the head and neck musculature. Laterally it is limited by the **supramastoid crest** (crista supramastoidea). The lower part of the nuchal surface is perforated by the **foramen magnum,** through which the spinal cord and associated structures enter the skull. Lateral to the foramen magnum are the **occipital condyles** (condyli occipitales), which articulate with the first cervical vertebra forming the **atlantooccipital joint** (articulatio atlantooccipitalis). The **paracondylar processes** (processus paracondylares) and the **nuchal tubercles** (tubercula nuchalia) are well developed in the dog and provide attachment to the head and neck musculature.

The roof of the skull can be divided into cranial and facial parts. The dorsal surface of the cranial part of the skull is formed by the paired external lamina of the narrow parietal part of the squamous occipital bone, the interparietal bone and the parietal bones and is continued rostrally by the paired frontal bones. A distinct external sagittal crest is found only in the cat and dolichocephalic breeds of dog, in which it continues along the parietal bone as the temporal line (linea temporalis). Its greatest width reaches the dorsal surface at the level of the orbit, where the **orbital ligament** (ligamentum supraorbitale) forms the fibrous supraorbital margin of the orbital wall (margo supraorbitalis) and attaches to the zygomatic process (processus zygomaticus) of the frontal bone.

The dorsal surface of the facial part of the skull is variable, depending on the breed. It is formed mainly by the paired nasal bones, complemented laterally by the rostral part of the maxilla and the nasal processes of the incisive bone. The concave rostral end of the dorsal surface of the nose is formed by the apices of the paired nasal bones.

The lateral surface of the cranial part of the skull varies greatly between the different breeds. Its prominent features are the zygomatic arches, the temporal fossa, the tympanic bulla, the orbital cavity and the pterygopalatine fossa.

The **zygomatic arch** (arcus zygomaticus) is the most prominent lateral projection in the cat and brachycephalic breeds of dog, whereas it is less prominent in dolichocephalic breeds. It extends as a convex arch rostrally towards the facial part of the skull below the orbit. It is formed by the **zygomatic bone** and the zygomatic process of the **squamous temporal bone,** which meet in an overlapping suture.

The transverse surface of the base of the zygomatic process articulates with the **temporomandibular joint.** The corresponding articulating surface of the mandible has two parts, the mandibular fossa and the distinct retroarticular process.

The concave **temporal fossa** (fossa temporalis), which forms the attachment of the temporal muscle, is formed by the temporal and parietal bones and the pterygoid plate of the basisphenoid bone. The frontal process of the zygomatic bone does not extend to the zygomatic process of the frontal bone. This leaves an opening in the dorsal orbital margin, which is closed by the orbital ligament.

F Frontal
I Incisive
L Lacrimal
M Maxilla
N Nasal
V Vomer
Z Zygomatic

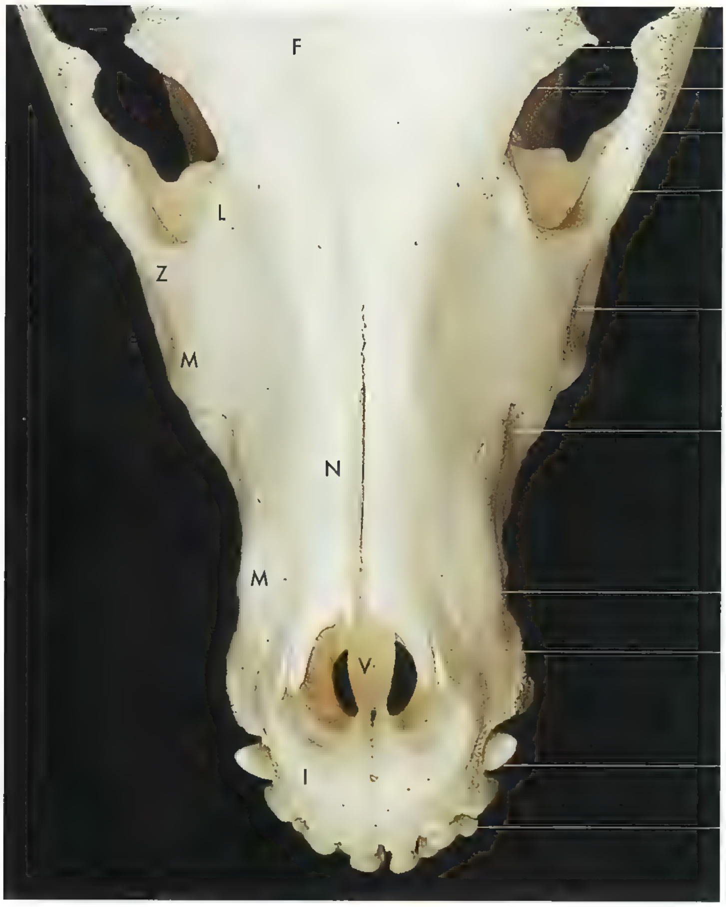

Fig. 1-46. Bones of the facial part of a canine skull (dorsal aspect).

The lateral surface forms structures of the **external auditory apparatus.** The **external acoustic meatus** is a short bony tube to which the external ear is attached and is closed by the **tympanic membrane,** which separates the canal of the external ear from the cavity of the middle ear. It is missing in the cat. Ventral and medial to the external acoustic meatus is the **tympanic bulla,** which encloses part of the cavity of the middle ear. Caudal to it, the **auditory canal,** through which the facial and stylomastoid nerves and the stylomastoid artery pass, exits through the **stylomastoid foramen.** The **otic notch** (incisura otica) is indistinct.

The bony **orbit** is the most prominent structure of the dorsal and lateral aspect of the skull, situated between its cranial and facial parts. The orbit is situated more laterally in the dog (79° angle between the orbital axis and the median plane) and more frontally towards the median plane in the cat (49° angle).

While the bony orbit is closed dorsally (margo supraorbitalis) by the **orbital ligament** (ligamentum orbitale), which ossifies in most cats, the osseous infraorbital margin is part of the zygomatic arch (Fig. 1-46). The rostromedial wall of the orbital cavity is formed by the lacrimal bone and contains the **lacrimal fossa,** which partially encloses the lacrimal sac. The **nasolacrimal duct** originates within the lacrimal fossa. The dorsomedial wall is excavated to form the distinct **trochlear fovea** (fovea trochlearis). The medial orbital wall is marked by three large openings: the **optic canal** (canalis opticus), the **orbital fissure** (fissura orbitalis) and the **rostral alar foramen** (foramen alare rostrale).

The optic opening is the portal of entry for the optic nerve and the internal ophthalmic artery. The external ophthalmic vein, the ophthalmic, oculomotor, trochlear and abducent nerves, which innervate the muscles of the eye pass through the orbital fissure. The maxillary nerve and artery pass, from the cranial cavity, through the rostral alar foramen and along the alar canal of the sphenoid bone. The artery and nerve then pass through the **pterygopalatine fossa** (fossa pterygopalatina), which forms the caudal opening to the infraorbital canal, just ventral to the orbital cavity (Fig. 1-47).

The **sphenopalatine foramen** is located caudal and ventral to the pteygopalatine fossa which communicates with the nasal cavity and the caudal palatine foramen, the opening of the palatine canal (Fig. 1-52).

The lateral surface of the facial part of the skull is formed by the maxilla and the incisive bone, complemented in dogs by parts of the zygomatic and lacrimal bones. The most prominent feature of the lateral facial surface is the **infraorbital foramen,** through which the infraorbital nerve leaves the infraorbital canal. The infraorbital canal is remarkably short in cats. The infraorbital foramen is easily palpable in the live dog and is located 1 cm dorsal to the third cheek tooth. In the cat, in which palpation is not possible, it is situated in the angle formed by the zygomatic arch and the maxilla.

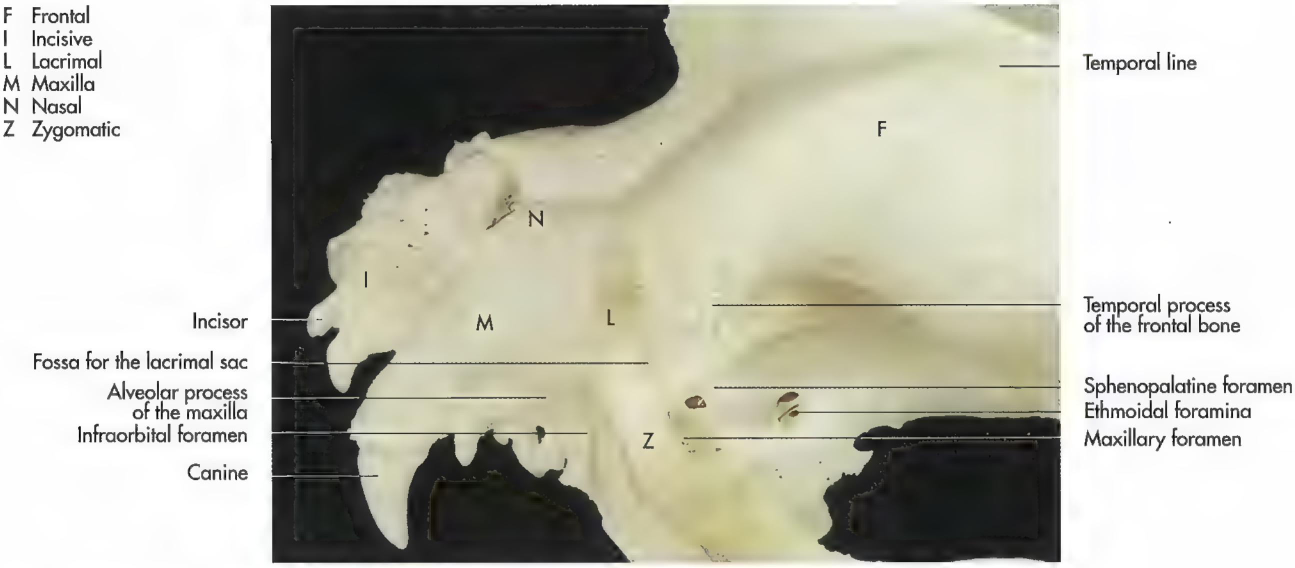

Fig. 1-47. Bones of the facial part of a brachycephalic dog (lateral aspect).

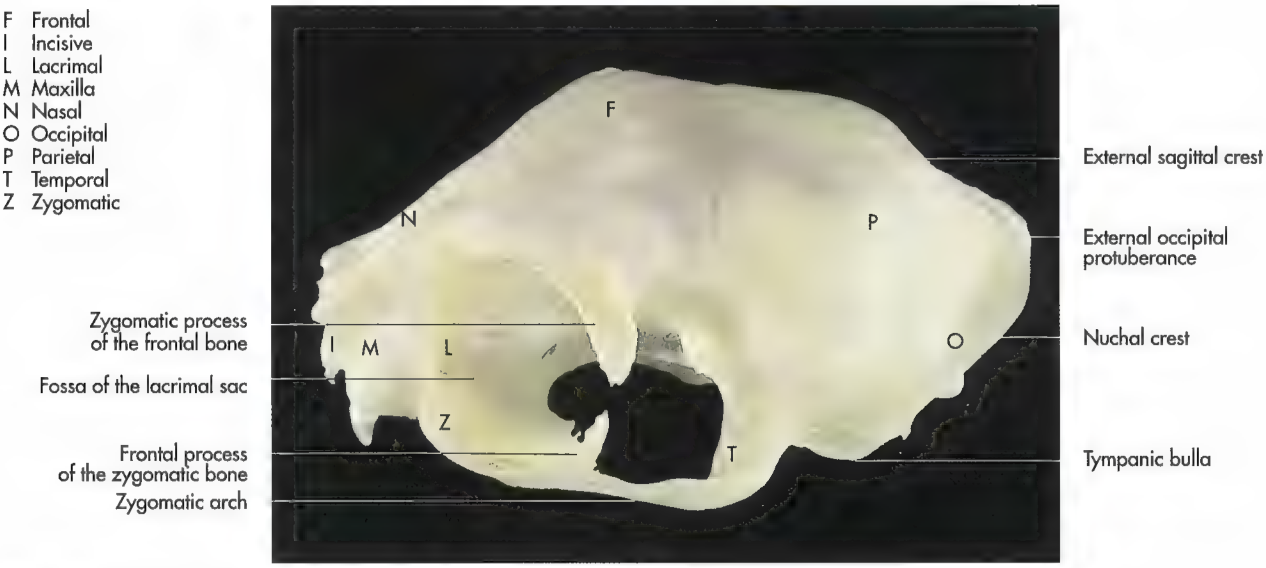

Fig. 1-48. Skull of a cat (dorsolateral aspect).

The ventral surface of the skull has three distinct regions: The **base of the cranium,** the **hard palate** and the **choanal region** between the nasal cavities and the pharynx.

The **base of the cranium** (basis cranii externa) is made up of the paired occipital condyles and the basilar part of the occipital bone, the bodies of the sphenoid bones and the wings and processes of the pterygoid bone. These are arranged into one horizontal plane, whereas the paracondylar processes extend beyond the base of the cranium ventrally and further ventrally in the dog than in the cat. Rostral to these, the base of the cranium is flat with the site of insertion of the flexors of the head central. It is perforated by various openings, through which the cranial nerves and vessels pass. The **canal of the hypoglossal nerve** (canalis nervi hypoglossi) opens rostral to the occipital condyles, and forms the exit for the like-named nerve (XII). The **jugular foramen** (foramen jugulare) through which the glossopharyngeal (IX), vagus (X) and accessory (XI) nerves pass, together with the internal carotid artery, is situated between the occipital bone and the tympanic bulla. The **oval foramen** (foramen ovale), through which the mandibular nerve (nervus mandibularis) emerges, opens at the junction between the occipital bone and the basisphenoid bone.

The **hard palate** (palatum osseum) is broad caudally and becomes more narrow rostrally. It is bordered by the dental alveoli, which are embedded in the alveolar processes of the maxilla and the incisive bone. The hard palate is formed mostly by the horizontal part of the palatine bone and complemented by those of the incisive bone. The **major palatine canal,** through which the like-named nerve and arteries pass, emerges at the paired **major palatine foramina** at the junction of the palatine bone with the maxilla. The **choanae** are

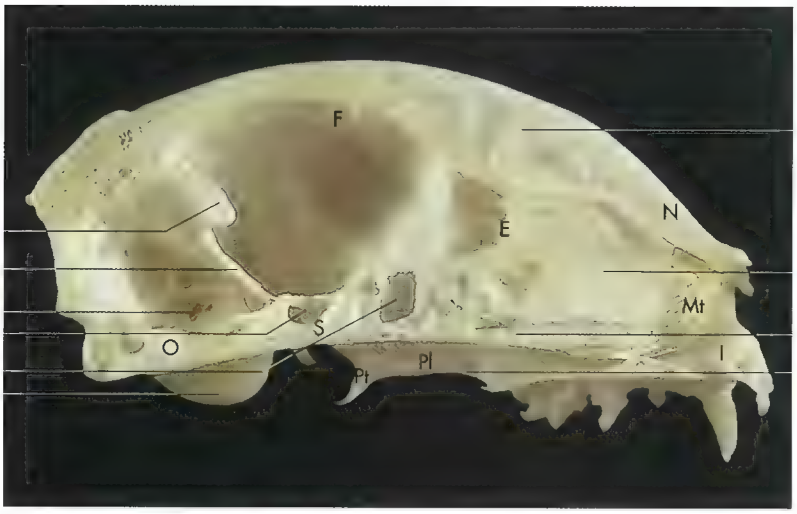

Fig. 1-49. Skull of a cat (medial aspect of sagittal section).

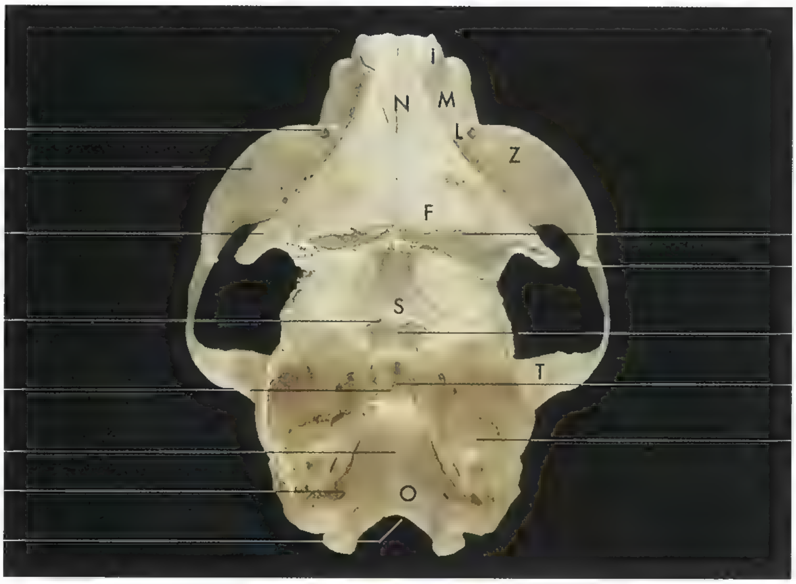

Fig. 1-50. Skull of a cat with calvaria removed (dorsal aspect).

the openings that lead from the nasal cavities to the pharynx and are especially long and narrow in dolichocephalic dogs. The choanal region is bounded by the perpendicular parts of the palatine and pterygoid bones laterally, which join the sphenoid bone and the vomer dorsally to form the choanal roof. The horizontal hard palate extends a fine process at its caudal margin, the caudal nasal spine (spina nasalis caudalis). The hook-shaped **hamulus** projects rostrally from the pterygoid bone (hamulus pterygoideus).

The **mandible** is a paired bone, which are firmly united rostrally by the fibrous tissue of the **mandibular symphysis** (articulatio intermandibularis). The body of each mandible extends to form the angular process caudally. Its ventral margin is convex without being indented by the **facial notch** (incisura vasorum facialium) which is typical for domestic mammals other than the carnivores. The alveolar margin of the mandibular body carries the dental alveoli for the cheek teeth (seven in the dog, three in the cat), the canine tooth and the three insisor teeth. The **interalveolar margin** (diastema) is comparatively short.

The lateral surface of the mandibular ramus is concave forming the **masseteric fossa,** which is bordered by the rostral and caudal mandibular crests (crista mandibularis rostralis et caudalis). The short condylar process carries the transversely elongated **head of the mandible** (caput mandibulae), which forms the **temporomandibular joint** by articulating with the temporal bone. The coronoid process extends beyond the condylar process dorsally and gives attachment to the temporal muscle.

The **ramus of the mandible** is perforated by the **mandibular canal,** through which the mandibular alveolar nerve passes. The mandibular canal begins caudally with the man-

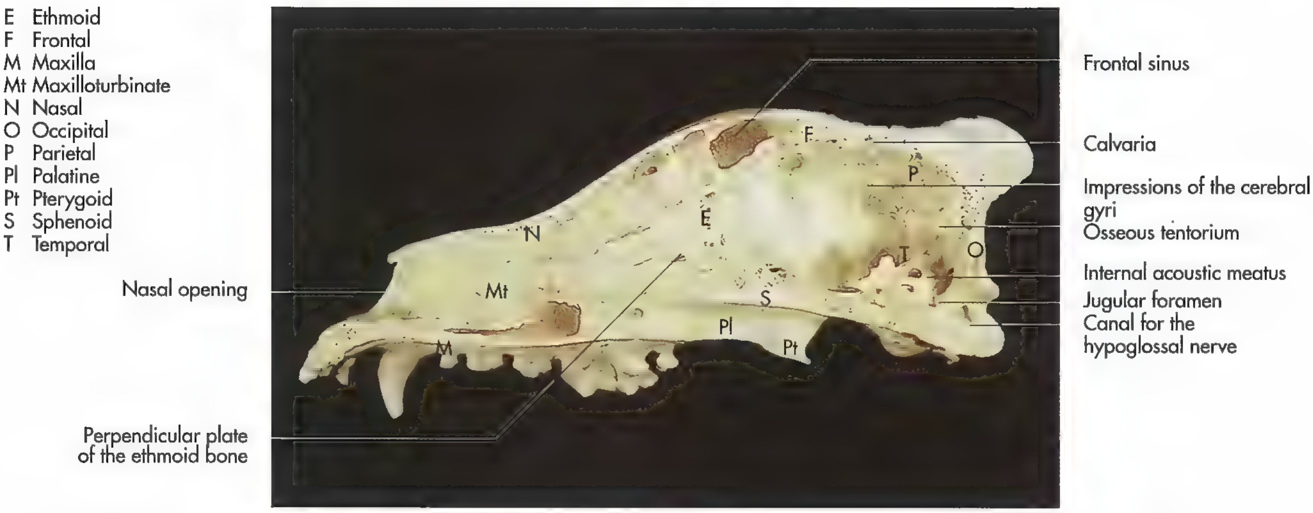

Fig. 1-51. Skull of a dog (median aspect of paramedian section).

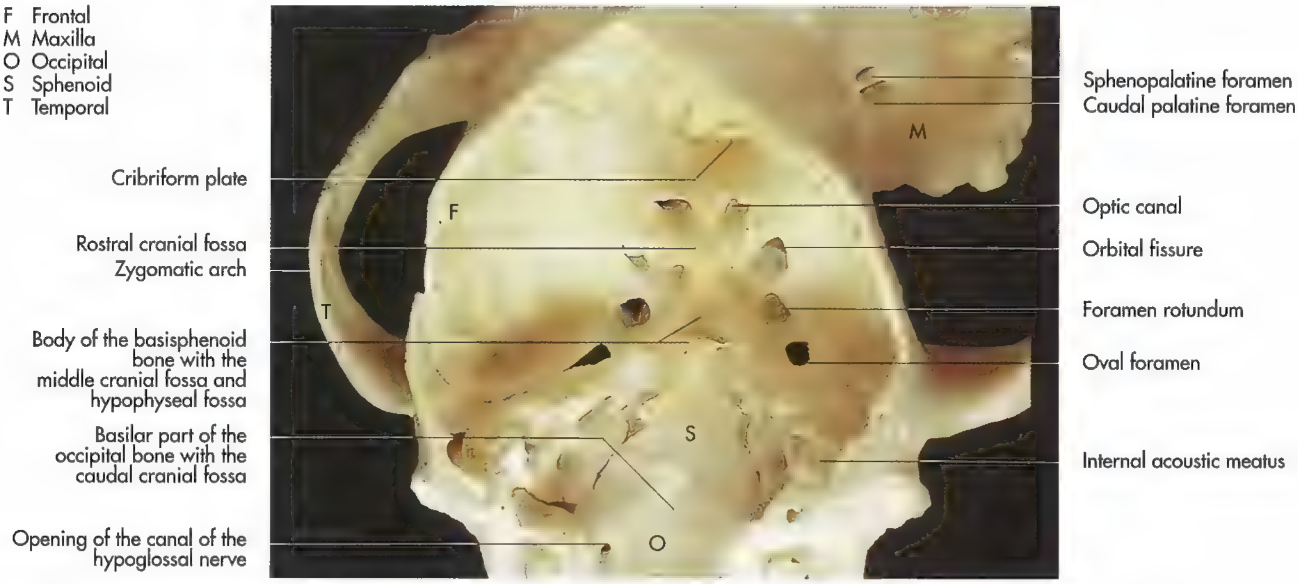

Fig. 1-52. Base of a canine skull (dorsal aspect).

dibular foramen on the medial surface of the ramus of the mandibular and emerges rostrally on the lateral surface of the interalveolar margin by means of the mental foramen. The latter foramen consists of two to three openings in carnivores. The mandibular canal continues rostrally to the dental alveoli of the incisor and canine teeth as the alveolar canal. In the dog the mental foramen can be located in the middle of the lateral surface ventral to the first cheek tooth, the mandibular foramen is found 2 cm caudal of the last mandibular cheek tooth.

Hyoid bone (os hyoideum)

The **hyoid bone** comprises the transverse, unpaired **basihyoid** (basihyoideum), each end of which articulates rostrodorsally with the paired **ceratohyoids** thus connecting to the suspensory part of the hyoid apparatus and caudally with the paired **thyrohyoid.** The thyrohyoid extends dorsocaudally to the thyroid cartilage of the larynx. The suspensory apparatus consists of the bony **epihyoid** and **stylohyoid** and the cartilagenous tympanohyoid joined together by cartilagenous tissue. The **tympanohyoid** joins the hyoid apparatus to the skull, by articulating with the **mastoid process of the petrosal part of the temporal bone,** which is situated caudal to the external acoustic meatus, forming a syndesmosis. This system of uniting the component parts by synchondroses provides the anatomical structure of the hyoid apparatus, which acts as a flexible suspensory mechanism between the base of the tongue, the skull and the larynx. The various elements of the bone can be visualised radiographically, but one has to remember that it takes at least two to three months post partum for the bones of the major part of the hyoid apparatus to ossify.

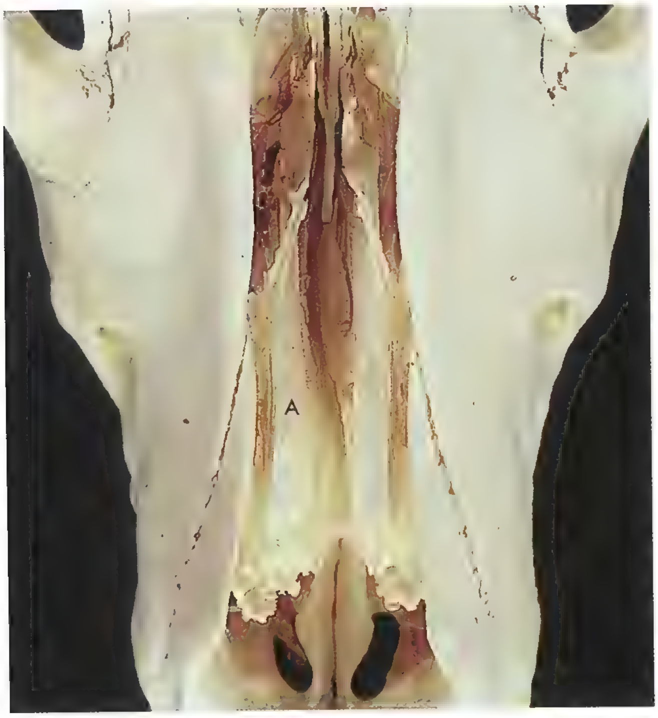

Fig. 1-53. Nasal cavity of a canine skull with dorsal wall removed, dorsal nasal conchae (A) and middle nasal conchae (dorsal aspect).

Fig. 1-54. Cranial part of a canine skull after the removal of the left side of the dorsal wall to show the frontal sinus (dorsal aspect).

Cavities of the skull

Cranial cavity (cavum cranii)

The **cranial cavity** is divided into a **larger rostral cavity,** which encloses the cerebrum and a **smaller caudal part** for the cerebellum. The separation of the two compartments is marked by the tentorium cerebelli osseum dorsally, the paired petrosal crests laterally and the dorsum sellae turcicae ventrally. The roof of the skull, the calvaria, consists of an external and an internal lamina, which encloses the frontal sinus in its rostral two thirds (Fig. 1-51). The internal surface of the cranial cavity has smooth **impressions** (impressiones digitatae) and irregular **elevations** (jugae cerebralia), which correspond to the sulci and gyri of the brain.

The **median internal sagittal crest,** to which the falx cerebri attaches, is low and smooth. It is accompanied on both sides by the groove for the dorsal sagittal sinus (sulcus sinus sagittalis dorsalis). These blood sinuses enter the osseous tentorium cerebelli (foramen sinus sagittalis) and pass through the canal of the transverse sinus (canalis sinus transversi), which leads, via the temporal canal, to the retroarticular foramen next to the external acoustic meatus. The temporal canal is absent in the cat.

The rostral wall is formed by the transversely orientated cribriform plate of the ethmoid bone and parts of the internal lamina of the frontal bone. The median crista galli is only present in the dorsal part of the cribriform plate, thus leaving a single ethmoidal fossa ventrally for the passage of the olfactory nerve bundles and blood vessels through the cribriform plate. The ethmoidal foramen, through which the ethmoidal nerve and external ethmoidal artery and vein emerge, is found either side of the cribriform plate. While these foramina are paired in the dog, there is only a single ethmoidal foramen in the cat.

The internal surface of the **base of the cranium** (basis cranii interna) is divided into three distinct fossae (Fig. 1-52). The relatively long **rostral cranial fossa** (fossa cranii rostralis) is formed mostly by the presphenoid bone and extends from the cribriform plate to the orbitosphenoidal crest (crista orbitosphenoidalis). It covers the **chiasmatic groove** (sulcus chiasmatis) of the optic chiasma and includes the paired optic canal, through which the optic nerves pass.

The **middle cranial fossa** (fossa cranii medialis) is separated from the **caudal cranial fossa** (fossa cranii caudalis) by the prominent dorsum sellae turcicae. The **hypophyseal fossa,** in which the **hypophysis** lies, is rostral to this. Either side of it are two deep fossae, which protect the piriform lobes (lobi piriformes) of the cerebrum. The middle cranial fossa is perforated by several different-shaped openings through which nerves and vessels pass (Fig. 1-52). These are, from rostral to caudal:

- **Orbital fissure** (fissura orbitalis), through which the oculomotor, trochlear and abducent nerves, and the anastomotic branch of the internal carotid artery pass.
- **Round foramen** (foramen rotundum), through which the maxillary nerve passes.
- **Oval foramen** (foramen ovale), through which the mandibular nerve and the middle meningeal artery pass.

Fig. 1-55. Radiograph of a feline skull (laterolateral projection) (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

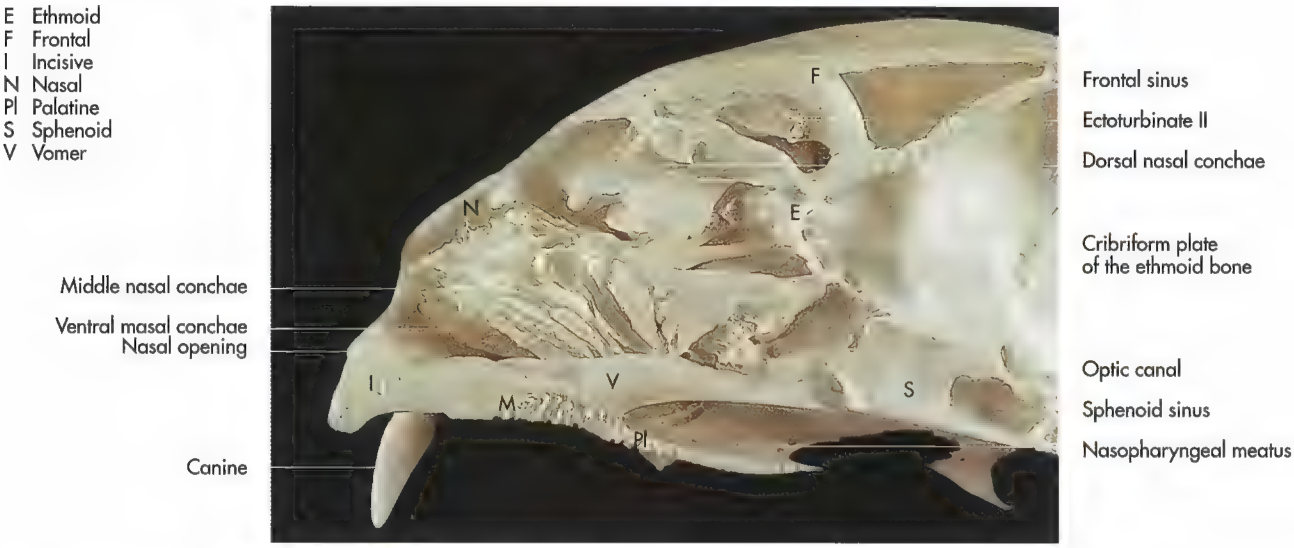

Fig. 1-56. Skull of a cat (median aspect of paramedian section).

The osseous structure of the caudal fossa of the cranium (fossa cranii caudalis) is formed by the basilar part of the occipital bone, bound laterally by the petrosal part of the temporal bone and extends caudally to the foramen magnum (Fig. 1-52). The internal surface has two cancave impressions (impressio pontina and Impressio medullaris). The **jugular foramen** (foramen jugulare), through which the glossopharyngeal, vagus and accessory nerves and in the dog, the internal carotid artery pass, is located close to the occipitotympanic suture.

Nasal cavity (cavum nasi)

The **nasal cavity** is the facial part of the respiratory tract and extends from the osseous **nasal opening** (apertura nasi ossea) to the **cribriform plate of the ethmoid bone.** It is separated longitudinally into two symmetric halves by the median nasal septum, which continues caudally in the perpendicular plate of the ethmoid bone and rostrally in the cartilagenous, flexible part of the nasal septum (pars mobilis septi nasi) (Fig. 1-56).

Each half of the nasal cavity contains the **nasal conchae** (conchae nasales) rostrally and the **ethmoturbinates** (ethmoturbinalia) caudally. The nasal cavity ends in the nasopharyngeal meatus, which leads to the nasal part of the pharynx (Fig. 1-56).

The **dorsal nasal concha** (concha nasalis dorsalis) is formed by the single basal leaf of the first endoturbinate, the **middle nasal concha** (concha nasalis media) is formed by the two spiral leaves of the second endoturbinate and the **ventral nasal concha** (concha nasalis ventralis) is formed by the maxillary turbinate (Fig. 1-56).

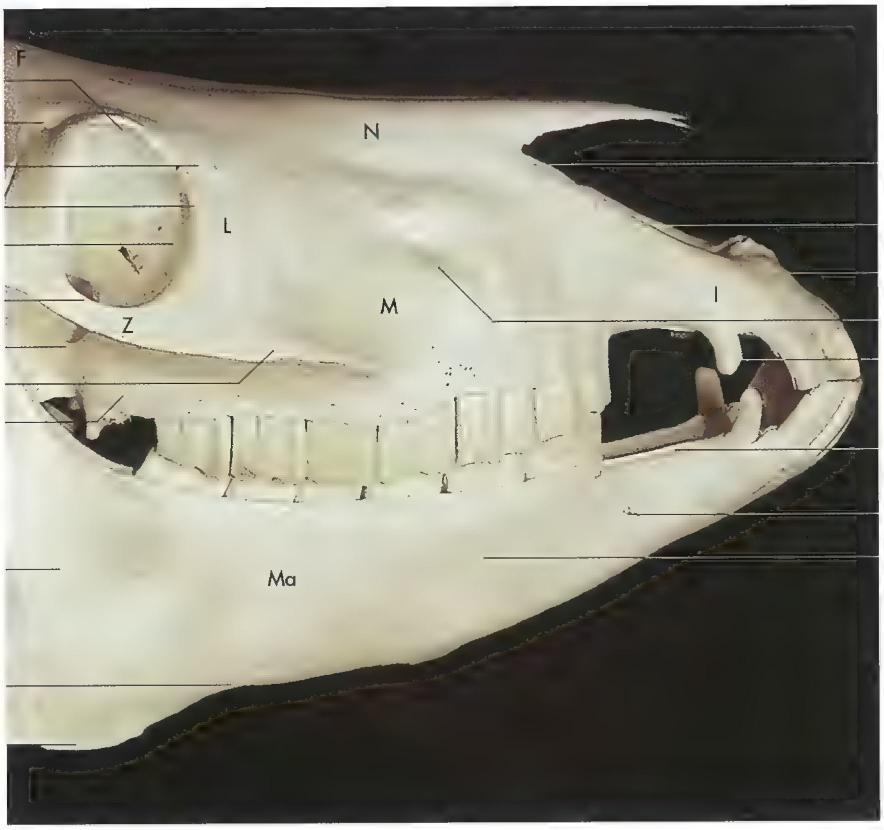

Fig. 1-57. Facial part of an equine skull (lateral aspect).

The **endoturbinates** are attached to the dorsal and lateral walls and the cribriform ethmoidal plate. The dog usually has four larger endoturbinates and six smaller ectoturbinates. The **first endoturbinate** is the most dorsal and provides the osseous structure of the dorsal nasal concha. It arises from the perpendicular plate of the ethmoid, attaches to the ethmoid crest (crista ethmoidalis) of the nasal bone and extends into the nasal cavity. The dorsal and ventral spiral leaf of the long second endoturbinate forms the middle nasal concha (Fig. 1-53 and 56). The **third** and **fourth endoturbinates** are extremely well-developed with the third being longer than the fourth.

The **ventral nasal concha** arises from the internal surface of the maxilla beginning at the level of the third cheek tooth reaching up to the nasal process of the incisive bone. The basal leaf divides into a ventral and a dorsal spiral leaf each of which extend secondary smaller leaves, which results in the extremely complex ethmoidal system.

The protruding nasal conchae divide the nasal cavity into the **dorsal nasal meatus** (meatus nasi dorsalis) between the dorsal nasal concha and the nasal roof, the **middle nasal meatus** (meatus nasi medius) between the dorsal nasal concha and the middle and ventral nasal conchae, which are arranged behind each other and the **ventral nasal meatus (meatus nasi ventralis)** between the middle and ventral nasal conchae and the nasal floor. The **common nasal meatus** (meatus nasi communis) is a slit-like space between the conchae and the nasal septum.

Paranasal sinuses (sinus paranasales)

The maxillary sinus of carnivores is better termed the **maxillary recess** (recessus maxillaris), since it is a large diverticulum of the nasal cavity at the level of the medial nasal conchae and not, like in the other domestic mammals, an air-filled cavity between the internal and external laminae of the bones of the skull. In the dog it is bound by the maxilla, the lacrimal bone, the palatine bone and the ethmoidal bone. The broad **nasomaxillary opening** (aditus nasomaxillaris) leads from the middle nasal meatus into the maxillary sinus.

In the dog the **frontal sinus** (sinus frontalis) is located in the rostral two thirds of the frontal bone and is divided into a rostral, lateral and medial compartment. They communicate with the nasal cavity via the space between the second and third ectoturbinate. The cat possesses an undivided frontal sinus and a palatine sinus on each side (Fig. 1-51 and 56).

The skull of the horse

The general shape of the equine skull is determined by the age, the sex and the breed of the animal. In foals the roof of the cranium is domed to match the contours of the brain, the facial part of the skull is short and shallow. The conformation of the adult skull develops as the facial part of the skull lengthens and deepens to accommodate the full set of teeth and the expanding paranasal sinuses. The enlargement of the frontal sinus largely influences the dorsal profile of the

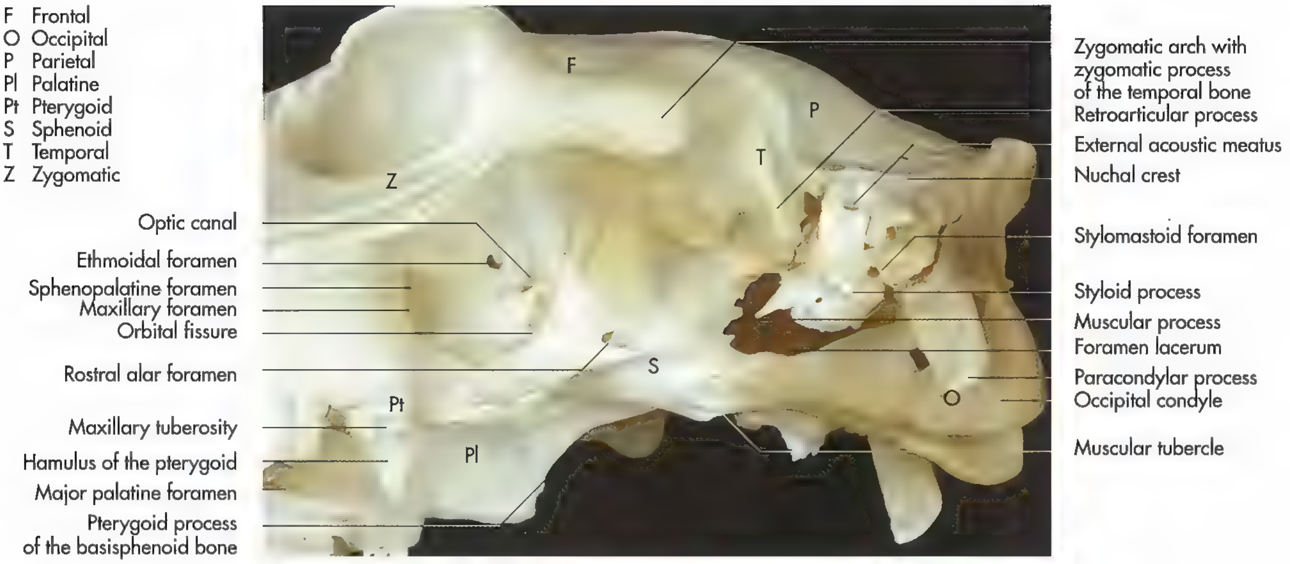

Fig. 1-58. Base of an equine skull (ventrolateral aspect).

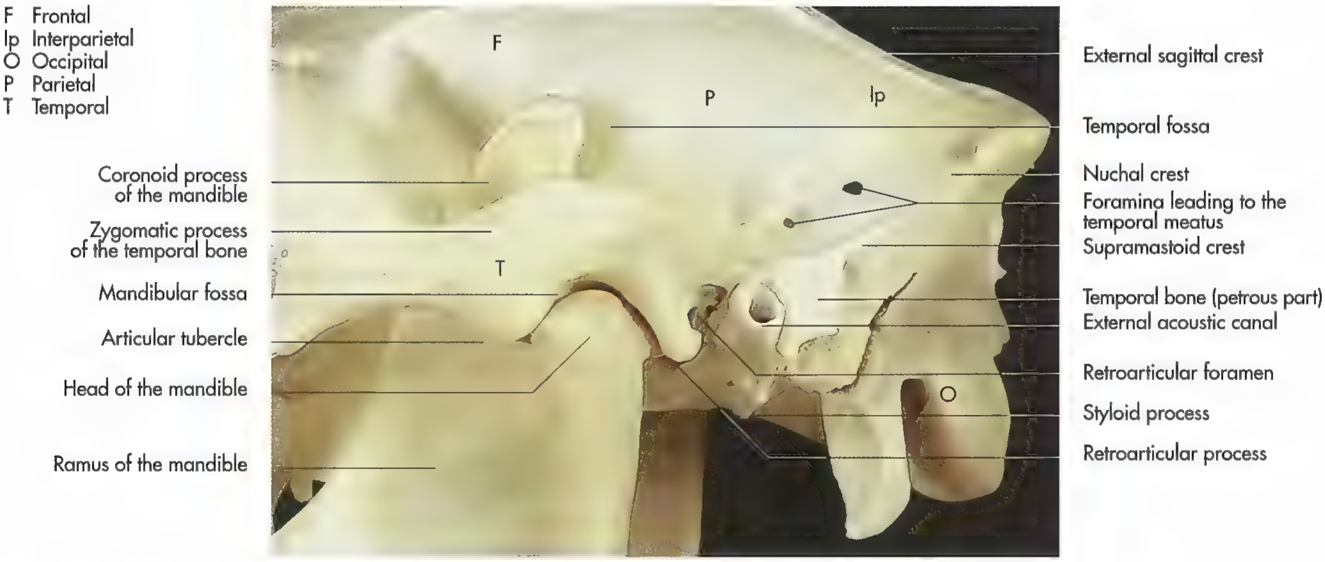

Fig. 1-59. Caudal part of an equine skull (lateral aspect).

nose and gives it its breed-specific appearance: A **convex profile** (ram's head) is typical for certain draft and warmblood horses, a **concave profile** (dished head) typical for Arabs and common in horses with a mixture of Arab blood (Fig. 1-57). Breed and sex specific characterisitcs become more pronounced in older horses.

The nuchal surface of the equine skull is formed by the squamous and the lateral parts of the occipital bone. It is separated from the dorsal surface by the **nuchal crest** (crista nuchae) and the **external occipital protuberance** (protuberantia occipitalis externa), both of which form the sites of attachment to the head and neck musculature. The external occipital protuberance continues laterally as the supramastoid crest (crista supramastoidea), bordering the nuchal surface.

The **foramen magnum,** through which the spinal cord passes, opens between the two occipital condyles, on the midline. The dorsal surface of the skull of the horse can be divided into a cranial and a facial region. The cranial part is formed by the squamous part of the occipital bone, the parietal and the interparietal bone, which are firmly fused with each other. The frontal bone lies rostral to these and is firmly fused to them by an osseous suture. The unpaired external sagittal crest, medial to the dorsal surface, bifurcates rostrally and then continues as the temporal line, forming part of the wall of the orbit. The roof of the skull is widest at the level of the supraorbital foramen, which is located at the base of the zygomatic process of the frontal bone. This process unites with the frontal process of the zygomatic bone, thus completing the bony supraorbital margin.

The major part of the facial region of the skull is formed by the paired nasal bones, complemented laterally by the maxilla and the nasal processes of the incisive bone. The rostral end of the dorsal surface of the nose is formed by the two apices of the paired nasal bones (processus rostrales).

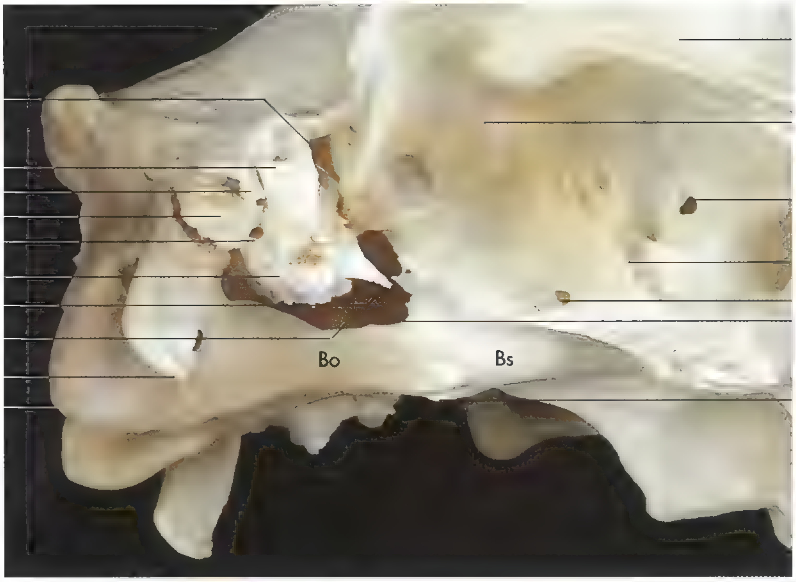

Fig. 1-60. Caudal part of an equine skull (ventrolateral aspect).

Like the dorsal surface, the lateral surface is also divisible in a cranial and facial region. The cranial part has the following features:

- Zygomatic arch (arcus zygomaticus),
- Temporal fossa (fossa temporalis),
- Orbit (orbita) and
- Pterygopalatine fossa (fossa pterygopalatina).

The **zygomatic arch** (Fig. 1-58) is strong and passes in a slight lateral bow, rostral by, to the facial part of the skull, covering the lateral aspect of the ventral part of the temporal fossa and the orbit. It is composed of the temporal process of the zygomatic bone and the zygomatic process of the temporal bone. The base of the latter forms the transverse articular surface of the **temporomandibular joint** (articulatio temporomandibularis). The articular area of this joint consists of the articular tubercle (tuberculum articulare) rostrally, the mandibular fossa (fossa mandibularis) in the middle and the retroarticular process (processus retroarticularis) caudally (Fig. 1-59).

The **temporal fossa** has a semicircular outline curving from the rostral to the laterobasal to the caudal aspects adjacent to the zygomatic arch, the supramastoid and the nuchal crest respectively. It forms the attachment to the temporal muscle.

The caudal aspect of the lateral surface is characterised by the **external parts of the ear** (auris) (Fig. 1-58 and 59). The **notch** into which the tube-shaped external acoustic canal protrudes with its wide opening (porus acusticus externus), lies caudal to the temporomandibular joint. The **retroarticular foramen** opens just rostral to the otic notch, and forms the opening to the **temporal canal** (meatus temporalis). The **styloid process** (processus styloideus), with which the hyoid bone articulates, is ventral to the retroarticular foramen. The canal through which the facial nerve passes (canalis nervi facialis), opens in the stylomastoid foramen, which is located caudal to the styloid process and through which the stylomastoid artery and vein and the facial nerve run after their passage through the middle ear.

The walls of the **orbital cavity** (Fig. 1-57) are composed of the frontal, lacrimal and zygomatic bones, the basisphenoid and the zygomatic process of the temporal bone. The orbits project almost laterally resulting in an angle of 115° between the orbital axis and the median plane. The osseous supraorbital margin has a fine edge and extends to the rostral and caudal lacrimal processes. At the medial canthus, the orbital wall is indented by the fossa for the lacrimal sac and the fossa for the ventral oblique muscle of the eye. The trochlear fovea and the fossa for the lacrimal gland are caudomedial to this, at the base of the zygomatic process of the frontal bone. There are several openings between the medial orbital wall, rostral to the pterygoid crest and the cranial cavity (Fig. 1-58).

These are, from dorsal to ventral:

- **Ethmoidal foramen** (foramen ethmoidale) close to the osseous suture formed by the frontal bone and the wing of the presphenoid, through which the ethmoidal nerve and external ethmoidal vessel pass.
- **Optic canal** (canalis opticus) through which the optic nerve passes.
- **Orbital fissure** (fissura orbitalis) for the passage of the ophthalmic, trochlear, occulomotor and abducent nerves, which innervate the muscles of the eye, and the external ophthalmic vein.
- **Round foramen** (foramen rotundum) for the maxillary nerve.
- **Rostral alar foramen** (foramen alare rostrale) through which the maxillary artery leaves the alar caudal and reaches the pterygopalatine fossa and
- **Caudal alar foramen** (foramen alare caudale) through which the maxillary artery enters.

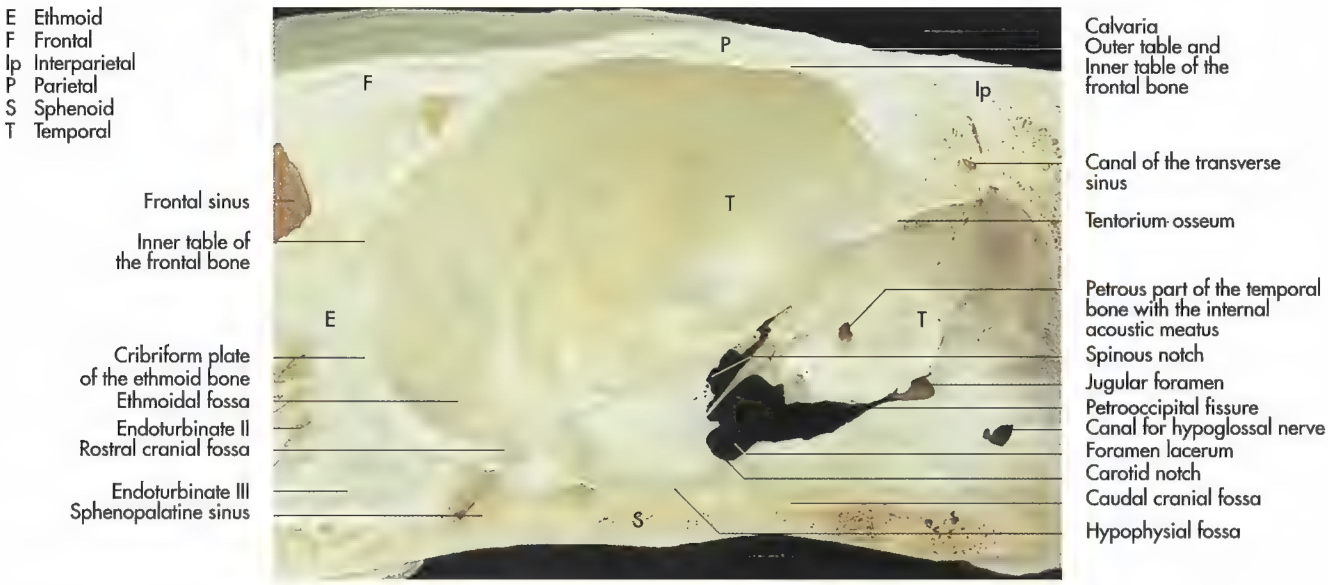

Fig. 1-61. Cranial cavity of a horse (medial aspect).

Ventral to the orbital cavity is the **pterygopalatine fossa** (fossa pterygopalatina) (Fig. 1-58), where the the large **maxillary foramen** (foramen maxillare) is located rostrally, through which the maxillary artery and nerve enter the infraorbital canal. Dorsomedially to it lie the **sphenopalatine foramen** (foramen sphenopalatinum), which leads into the nasal cavity and the **caudal palatine foramen** (foramen palatinum caudale), the opening of the palatine canal. Both these foramen enclose branches of the maxillary artery, vein and nerve. The **pterygopalatine fossa** is formed by the maxillary tuberosity laterally and the perpendicular part of the palatine bone medially.

The lateral surface of the facial part of the skull is composed of the maxilla, the incisive, the nasal, the zygomatic and the lacrimal bones. The most prominent features of the lateral facial surface are the **infraorbital foramen** (foramen infraorbitale) and the **facial crest** (crista facialis) (Fig. 1-57). The infraorbital foramen is the opening through which the infraorbital nerve and vessels leave the infraorbital canal. It is easily palpable through the overlying skin, the levator of the upper lip and nasolabial levator muscle (m. levator labii superficialis, m. levator nasolabialis) in the live animal 3 cm dorsal to the facial crest and 2 cm rostral to the rostral end of it. The facial crest is a prominent bony ridge on the lateral surface of the maxilla, which is continuous caudally with the zygomatic arch.

The basal surface of the skull consists of a cranial, choanal and palatine region, which are arranged behind each other in a horizontal plane.

The external surface of the base of the skull is limited caudally by the occipital condyles, which are separated by the **intercondylar notch** (incisura intercondylaris). Rostrolateral to the occipital condyles and separated from them by the deep ventral condylar fossa are the hook-shaped, laterally compressed paracondylar processes. The medial wall of the ventral condylar fossa bears the hypoglossal canal, through which the like-named nerve passes. The median muscular tubercle to which the head and neck musculature attaches is situated on the border between the base of the occipital bone and the basisphenoid.

The base of the skull is characterised by several openings through which cranial nerves and vessels pass. The **jugular foramen** opens between the base of the occipital bone and the tympanic bulla, caudal to the petro-occipital fissure. Rostrally lies the **foramen lacerum,** through which caudal extent the glossopharyngeal (IX), the vagus (X), and the accessory (XI) nerve pass (Fig. 1-61).

The rostral part of the foramen lacerum is sharply bordered by the expansive wing of the basisphenoid and is subdivided in several notches (incisura carotica, ovalis and spinosa) that allow the passage for the internal carotid artery, the mandibular nerve (V_3) and the middle meningeal artery, respectively (Fig. 1-61).

The **hard palate** (palatum osseum) is relatively long and narrow (Fig. 1-62). It is bordered by the dental alveoli for the six (or seven) upper cheek teeth, which are part of the alveolar processes of the maxilla and the incisive bone. The interalveolar margin carries the socket for the canine tooth and rostral to it are the dental alveoli for incisor teeth. A minor part of the hard palate is formed by the horizontal plates of the palatine bones, the rest is formed by the horizontal parts of the incisive bone and the maxilla. The palatine canal opens in the paired major palatine foramen, where the narrow palatine bone joins the maxilla. The major palatine nerve and vessel exit at this foramen.

The **choanae** (Fig. 1-62) are the openings, which lead from the nasal cavities to the nasopharynx. The choanal region is bordered laterally by the perpendicular plates of the palatine and pterygoid bones, and dorsally by parts of the sphenoid bone and the vomer caudally. The prominent **pterygoid hamulus,** a hook-shaped process, projects from the pterygoid bone, while the caudal nasal spine is an extension of the choanal margin of the horizontal palatine plate.

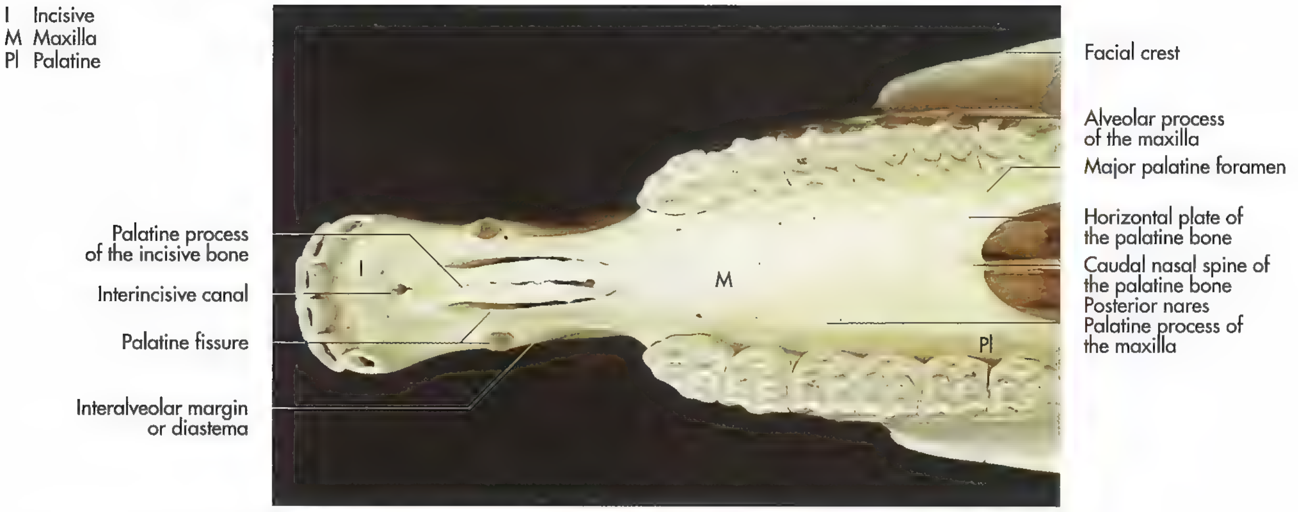

Fig. 1-62. Bones of the hard palate of a horse (ventral aspect).

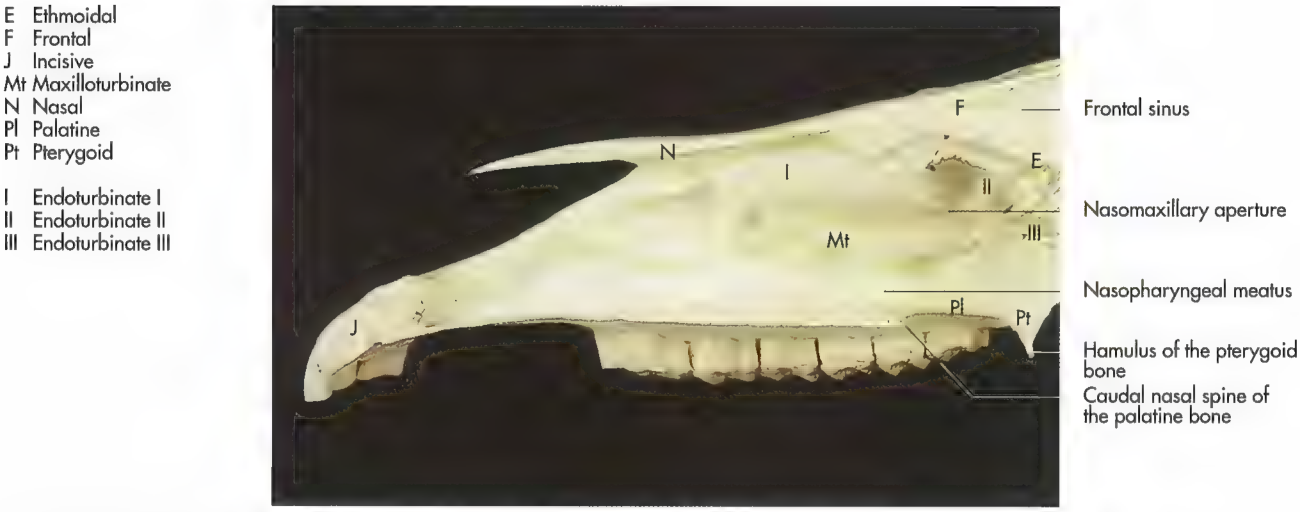

Fig. 1-63. Facial part of an equine skull (medial aspect of paramedian section).

The two mandibles (Fig. 1-37) are firmly fused at the **mental angle** (angulus mentalis) forming the mandibular symphysis, which becomes undetectable at two years of age. The body of the mandible has a roughening for the attachment of the sternomandibular muscle (tuberositas sternomandibularis) caudodorsal to the mandibular angle. Its alveolar border carries the sockets for the six cheek teeth, its interalveolar border, the socket for the canine tooth and its incisive part, for the three incisor teeth. A prominent vascular notch, the facial notch (incisura vasorum facialium), marks the ventral border, where the facial vessels pass onto the lateral surface of the face .

The condylar process ends dorsally in the transversely orientated mandibular head and the coronoid process projects far into the temporal fossa. The mandibular canal can be entered via the mandibular foramen on the lateral aspect of the mandibular ramus by drawing an imaginary line from the condylar process to the rostral border of the facial notch (Fig. 1-57). The mandibular nerve leaves the mandibular canal through the mental foramen as the mental nerve, which can be palpated on the lateral surface 1 cm ventral to the interalveolar margin at the level of the labial commissure. The mental nerve is accompanied by the mental vessels.

Hyoid bone (os hyoideum)

A substantial median **lingual process** (processus lingualis) projects from the transverse basihyoid into the root of the tongue (Fig. 1-41). From each end of the basihyoid extend the thyrohyoids caudally to the thyroid cartilage of the larynx. The paired ceratohyoid articulates with the osseous epihyoid, which itself is firmly fused to the osseous stylohyoid and the cartilagenous tympanohyoid in the adult horse. The latter joins the hyoid apparatus to the head by forming a syndesmosis with the styloid process of the tympanic part of the temporal bone.

Fig. 1-64. Frontal and maxillary sinuses of a horse (lateral aspect).

Fig. 1-65. Frontal and maxillary sinuses of a horse (dorsal aspect).

Cavities of the equine skull

Cranial cavity (cavum cranii)

The cranial cavity is divided into a larger compartment rostrally, which encloses the cerebrum and a smaller compartment caudally for the cerebellum. The limits of these two cavities are indicated dorsally by the osseous tentorium cerebelli and laterally by the paired crests of the petrous temporal bone. The rostral third of the **roof of the skull** (calvaria) (Fig. 1-61) encloses the frontal sinus between its internal and external plates. The internal surface is marked by various **depressions** (impressiones digitatae, jugae cerebralia), which match the sulci and gyri of the brain. The median internal sagittal These grooves lead to the transverse sinus canal, which itself ends in the temporal meatus, and finally open in the retroarticular foramen, close to the external acoustic meatus. The rostral wall of the cranial cavity is formed by the cribriform plate of the ethmoidal bone and parts of the internal plate of the frontal bone (Fig. 1-61). The **cribriform plate** is divided into two deep **eth-**

moidal fossae by a well-developed median ridge, the crista galli. They are peforated to allow the passage of the olfactory nerve bundles and also present the foramina for the ethmoidal nerve and the external ethmoidal artery and vein.

The internal surface of the **base of the cranium** (basis cranii interna), (Fig. 1-61) is divided into three regions. The rostral cranial fossa (fossa cranialis rostralis) lies at a more dorsal level than the following middle fossa and extends from the cribriform plate to the orbitosphenoidal crest; it forms a bony shelf, which covers the optic canal at the **optic chiasm** (chiasma opticum). The demarcation between the middle cranial fossa (fossa cranialis media) and caudal cranial fossa (fossa cranialis caudalis) is indistinct. The middle cranial fossa is concave, forming the hypophyseal fossa, which encloses the hypophysis, and the piriform fossa, which encloses the piriform lobes. On either side there are two grooves extending to the orbital fissure, through which the ophthalmic, occulomotor and abducent nerves pass. The inner surface of the base of the cranium is marked by the following, through which nerves and vessels pass:

- **Orbital fissure** (fissura orbitalis) medially for the passage of the ophthalmic, occulomotor and abducent nerve,
- **Round foramen** (foramen rotundum) laterally for the maxillary nerve,
- **Trochlear foramen** (foramen trochleare) for the trochlear nerve.

The basioccipital and the petrosal part of the temporal bone form the caudal cranial fossa (fossa cranii caudalis) (Fig. 1-61). It extends to the foramen magnum and its internal surface has several shallow depressions. The laterobasal wall is perforated by the foramen lacerum and its caudal part by the jugular foramen. Rostrally the foramen lacerum is provided with three notches (mediolaterally): the carotid (for the internal carotid artery), the oval (for the mandibular nerve, V_3), and the spinous (for the middle meningeal artery). The glossopharyngeal (IX), vagus (X) and accessory (XI) nerves exit through the jugular foramen. Its base presents the entrance to the canal for the hypoglossal nerve.

Nasal cavity (cavum nasi)

The **nasal conchae** of the equine skull differ widely from those of the other domestic mammals (Fig. 1-24 and 36). The spiral leaf of the first endoturbinate forms two compartements: the rostral part scrolls ventrally and demarcates the dorsal conchal recess, whereas the caudal part encloses the dorsal conchal sinus. This sinus is continuous with the frontal sinus; the combined sinuses are termed **conchofrontal sinus** (sinus conchofrontalis). There is no direct communication between this sinus and the nasal cavity, but they communicate indirectly via the caudal maxillary sinus.

The maxilla provides the osseous border for the **ventral nasal concha** (os conchae nasalis ventralis). It scrolls dorsally, forming the ventral conchal recess rostrally and the ventral conchal sinus caudally. The latter communicates with the rostral maxillary sinus. The entire ethmoidal labyrinth comprises **six endoturbinates** and **25 ectoturbinates** in the horse. The first endoturbinate extends further rostrally than the other, more ventrally located turbinates. The second endoturbinate is short and contains the middle conchal sinus, which communictaes with the caudal maxillary sinus. The ectoturbinates are arranged in two rows, a lateral row with smaller and a medial row with larger turbinates.

Paranasal sinuses (sinus paranasales)

The following paranasal sinuses are present in the adult horse (Fig. 1-63 to 65):

- **Caudal maxillary sinus** (sinus maxillaris caudalis),
- **Rostral maxillary sinus** (sinus maxillaris rostralis),
- **Conchofrontal sinus** (sinus conchofrontalis), which is subdivided into a **dorsal conchal sinus** (sinus conchae dorsalis) and a **frontal sinus** (sinus frontalis),
- **Sphenopalatine sinus** (sinus sphenopalatinus) and
- **Ventral conchal sinus** (sinus conchae ventralis).

The larger **caudal maxillary sinus** (sinus maxillaris caudalis) is accommodated within the caudal part of the maxilla, the lacrimal bone and the zygomatic bone. The smaller **rostral maxillary sinus** (sinus maxillaris rostralis) lies entirely within the rostral part of the maxilla. The two maxillary sinuses are separated from each other by a bony septum. This **septum** (septum sinuum maxillarium) is commonly situated about 4–6 cm from the rostral end of the facial crest. The floor of the maxillary sinuses is indented by the dental alveoli for the last three cheek teeth.

Further medially a sagittally orientated bony plate, which includes the infraorbital canal at its free margin, projects into the maxillary sinuses and divides them into a medial and a lateral compartment. Both sinuses share a slit-like opening towards the middle nasal meatus, the **nasomaxillary aperture** (apertura nasomaxillaris), which is located at the level of the fifth cheek tooth in the adult horse (Fig. 1-63). The caudal maxillary sinus communicates directly or indirectly with all the other paranasal sinuses.

This anatomical arrangement accounts for the spread of infection throughout the paranasal sinuses. The caudal maxillary sinus communicates with the conchofrontal sinus through the **frontomaxillary opening** (apertura frontomaxillaris) at the level of the lacrimal duct. The conchofrontal sinus consists of the dorsal conchal sinus and the frontal sinus. The union of the palatine and the sphenoidal sinus results in the combined sphenopalatine sinus. The rostral maxillary sinus communicates with the ventral conchal sinus through the conchomaxillary opening (apertura conchomaxillaris), which can be entered via the infraorbital canal.

Vertebral column or spine (columna vertebralis)

The **vertebral column** is composed of a series of unpaired bones, the vertebrae, the number of which varies between domestic mammals. Although the vertbrae of the different re-

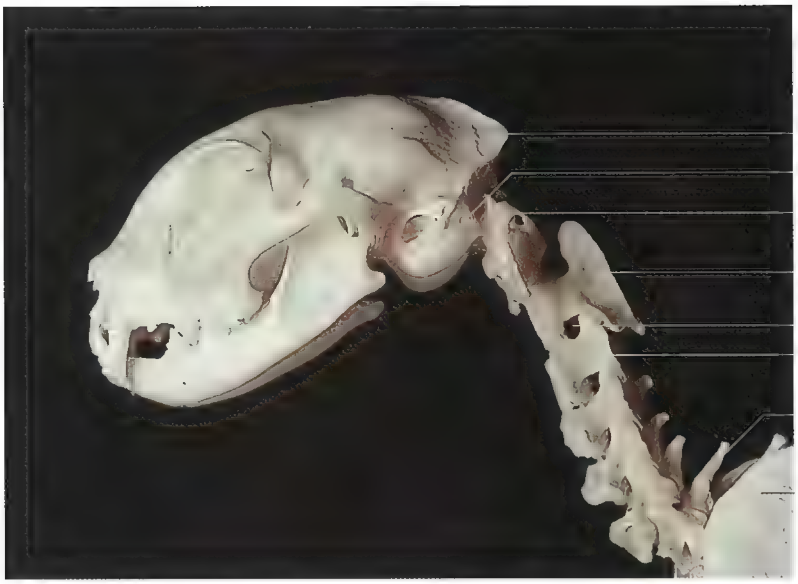

Fig. 1-66. Skull and cervical spine of a cat (lateral aspect).

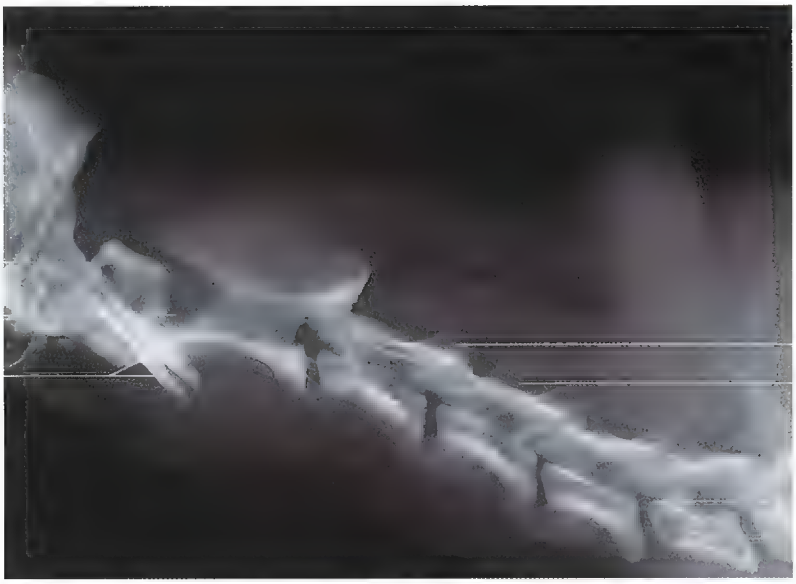

Fig. 1-67. Radiograph of the cervical spine of a dog (laterolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

gions (cervical, thoracic, lumbar, sacral and caudal vertebrae) have to fulfil different functions and therefore have individual characteristics, all vertebrae share a common basic structure (Fig. 1-68). The vertebrae are classified as **short bones (ossa brevia)** with spongy substance (substantia spongiosa) in the center and compact bone (substantia compacta) around it.

Each vertebra consists of:

- Body (corpus vertebrae),
- Arch (arcus vertebrae),
- Processes (processus vertebrae).

The **body** is the prismatic or cylindrical ventral part of a vertebra on which the other parts are constructed. Each vertebral body has a convex cranial (extremitas cranialis) and a concave caudal (extremitas caudalis) extremity, which are covered by a plate of hyaline cartilage, forming the unossified part of the epiphysis of the vertebral body (Fig. 1-68).

Intervertebral fibrocartilagenous discs (disci intervertebralis) are interposed between adjacent vertebrae. The dorsal surface of the body of the vertebrae is marked by longitudinal grooves, nutritional foramina and a median ridge for ligamentous attachment. The ventral surface carries the **ventral crest** (crista ventralis), which varies in size in the different regions of the vertebral column.

The **vertebral arch** or **neural arch** forms over the dorsal surface of the vertebral body, thus completing the enclosure of a **vertebral foramen** (foramen vertebrale) (Fig. 1-68). Each vertebral arch is made up of two lateral pedicles (pediculus arcus vertebrae) and a dorsal plate (lamina arcus verte-

Fig. 1-68. Cervical vertebra of an ox (cranial aspect).

brae). The vertebral foramina correspond with that of adjacent vertebrae to form the **vertebral canal** (canalis vertebralis), which surrounds the spinal cord, its meninges, spinal nerves, blood vessels, ligaments, fat and connective tissue.

The diameter of the vertebral canal is greatest at the level of the first and second cervical vertebrae. It is reduced in width throughout the cevical spine, increases again in the cranial thoracic region and becomes narrower in the caudal thoracic region. The diameter widens again in the lumbar region and gradually becomes narrower at the level of the first caudal vertebra.

Remnants of a **ventral arch** are found on the caudal vertebrae of cats, dogs and ruminants (Fig. 1-102).

The bases of the pedicles are notched (incisura vertebralis cranialis and caudalis). When successive vertebrae articulate, the notches on either side of adjacent vertebrae outline the intervertebral foramina (foramina intervertebralia), through which the spinal nerves pass (Fig. 1-66 and 67).

Dorsally most of the vertebral arches fit closely without leaving a space. Yet there are three sites in the vertebral column where an aperture (spatium interarcuale) is formed between the arches of adjacent vertebrae (Fig. 1-67 and 79). These are of clinical importance, since they can be used to enter the vertebral canal for injections or obtaining samples of cerebrospinal fluid:

- **Atlantooccipital space** (spatium atlantooccipitale) between the occipital bone and the first vertebra (atlas),
- **Atlantoaxial space** (spatium atlantoaxiale) between the first (atlas) and the second vertebra (axis),
- **Lumbosacral space** (spatium lumbosacrale) between the last lumbar vertebra and the sacrum.

Each vertebra carries a number of processes (processus vertebrae) for the attachment of muscles and ligaments and for the articulation with adjacent vertebrae. The following processes can be present (Fig. 1-68):

- **dorsal** or **spinous process** (processus spinosus) at the mid-dorsal line of the vertebral arch,
- two **transverse processes** (processus transversi), projecting laterally from the base of the vertebral arch,
- four **articular processes** (processus articulares caudales et craniales), positioned cranial and caudal to the root of the spinous process,
- two **mammilary processes** (processus mamillares) between the transverse and cranial articular processes of the thoracic and lumbar vertebrae.

Additional processes are found in some species:

- two **accessory processes** (processus accessorii) between the transverse and the caudal articular processes of the last thoracic vertebrae (carnivores and pigs) and the lumbar vertebrae (carnivores).

The numbers of vertebrae that compose each region is characteristic for the different species (Tab. 1-2).

Cervical vertebrae (vertebrae cervicales)

The **first** (atlas) and **second** (axis) **cervical vertebrae** are highly modified to allow free movement of the head (Fig. 1-66, 1-67, 69 to 72 and 79). The atlas apparently possesses no body, but consists of two lateral masses (massae laterales) joined by dorsal and ventral arches (arcus dorsalis et ventralis), which constitute a bony ring. The **dorsal tubercle** (tuberculum dorsale) is located on the cranial end of the dorsal arch and the **ventral tubercle** (tuberculum ventrale) on the caudal end of the ventral arch. An expanded **transverse process** (processus transversus) projects laterally from each mass (massa lateralis), these shelf-like processes are termed the **wings of the atlas** (alae atlantis) (Fig. 1-69 to 73).

The **ventral aspect** of the wing is hollowed to form the **atlantic fossa** (fossa atlantis). Its base is peforated by the **alar foramen** (foramen alare), or in carnivores by the **alar notch** (in-

Fig. 1-69. First cervical vertebra (atlas) of a dog (dorsal aspect).

Fig. 1-70. First cervical vertebra (atlas) of a pig (dorsal aspect).

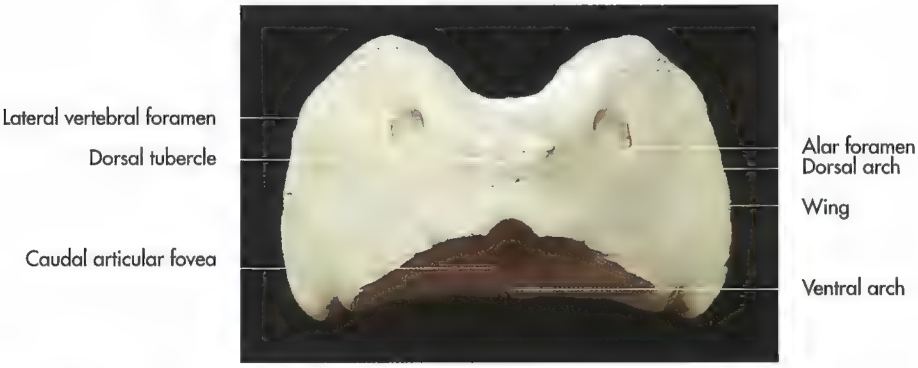

Fig. 1-71. First cervical vertebra (atlas) of an ox (dorsal aspect).

Fig. 1-72. First cervical vertebra (atlas) of a horse (dorsal aspect).

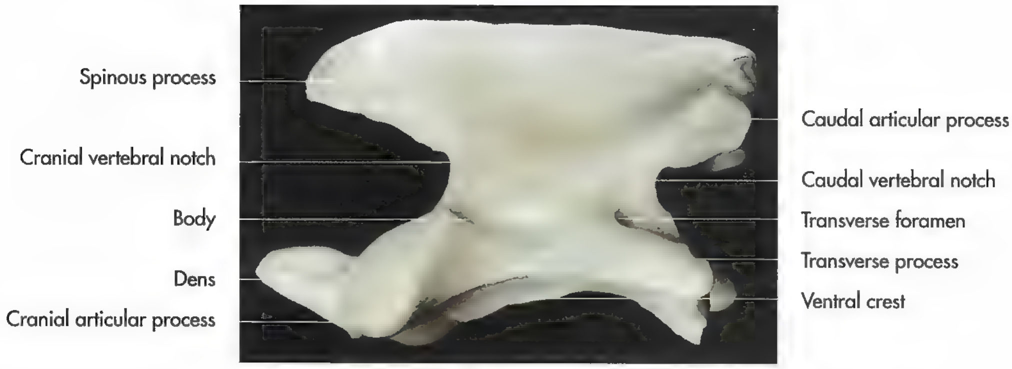

Fig. 1-73. Second cervical vertebra (axis) of a dog (lateral aspect).

Fig. 1-74. Second cervical vertebra (axis) of a pig (lateral aspect).

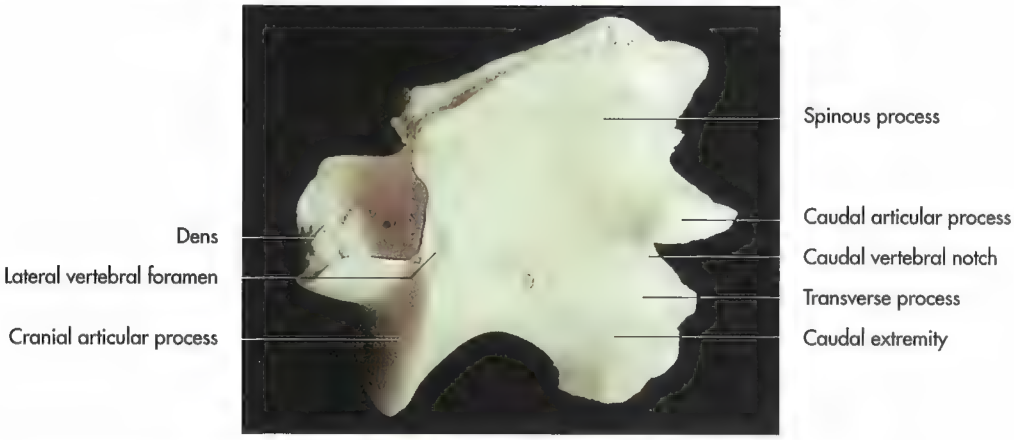

Fig. 1-75. Second cervical vertebra (axis) of an ox (lateral aspect).

Fig. 1-76. Second cervical vertebra (axis) of a horse (lateral aspect).

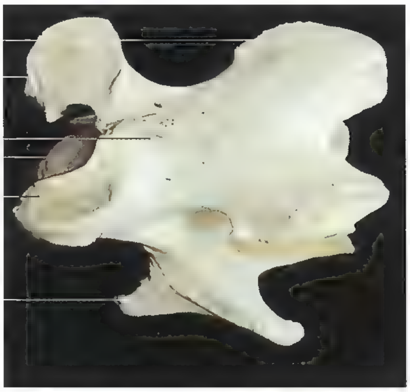

Fig. 1-77. Third cervical vertebra of a horse (dorsolateral aspect).

Fig. 1-78. Sixth cervical vertebra of a pig (craniolateral aspect).

cisura alaris). The **lateral vertebral foramen** (foramen vertebrale laterale) opens in the craniodorsal part of the vertebral arch. The **transverse foramen** (foramen transversarium) is a short canal passing through the caudal part of the wing of the atlas (Fig. 1-69 to 73). It is not present in ruminants.

The cranial aspect of the ventral arch of the atlas is excavated (fovea articularis cranialis) to articulate with the occipital condyles (condyli occipitalis) of the occipital bone. The dorsal surface of the ventral arch has a caudal transverse concave articular surface, the **fovea dentis,** which articulates with the **dens** of the second cervical vertebra. The fovea dentis blends with the shallow articular areas on the caudal surface of the lateral masses (fovea articulares caudales), that articulate with the cranial articular processes of the second cervical vertebra (Fig. 1-71 and 72).

The atlas is modified in form and structure to match its functions. The extended transverse processes, the **wings** (alae atlantis) provide attachment to the dorsal and ventral musculature, which is responsible for up-and-down movement of the head and constitutes the muscular connection between the spine and the nuchal aspect of the occipital bone. The caudal articular surface of the atlas articulates with the second cervical vertebra. The lateral free margin of the wings of the atlas furnish attachment to those head and neck muscles, which are primarily responsible for rotary movements of the head. The wide joint spaces of the atlantooccipital and the atlantoaxial joint support relatively free vertical and rotational movements.

The **second cervical vertebra** (axis) constitutes the pivot around which the atlas, and thus the head rotates (Fig. 1-73 to 76). Its **cylindrical body** (corpus vertebrae) carries a well-developed **ventral crest** (crista ventralis). The cranial extremity of the body is characterised by the centrally located **dens,** which is regarded as the displaced body of the atlas based on its development. It is rodlike in carnivores and more spout like in other species, matching the fovea dentis of the atlas. The **ventral articular surface of the dens** (facies articularis ventralis dentis) is confluent with the **cranial articular surfaces** (facies articularis cranialis) in the horse and ox, but separate in the other domestic mammals. The **caudal articular surface** (facies articularis caudalis) is smooth and concave and faces towards the intervertebral disc.

The **arch** (arcus vertebrae) of the axis carries the elongated, expanded **spinous process** (processes spinosus), which overhangs the cranial and caudal end of the vertebral body in carnivores and only the caudal end in the pig. It is a rectangular bony plate in ruminants and bifurcates caudally in the horse. Corresponding to the spinous process the caudal vertebral notch (incisura vertebralis caudalis) is large. The spinous process is confluent with the caudal articular processes in carnivores and horses, but remains separate in ruminants and the pig (Fig. 1-73 to 76).

Tab. 1-2. Vertebral formula of the domestic mammals.

	Carnivores	Pig	Ox	Small ruminants	Horse
Cervical vertebrae	7	7	7	7	7
Thoracic vertebrae	12–14	13–16	13	13	18
Lumbar vertebrae	(6) 7	5–7	6	6	5–7
Sacral vertebrae	3	4	5	(3) 4–5	5
Caudal vertebrae	20–23	20–23	18–20	13–14	15–21

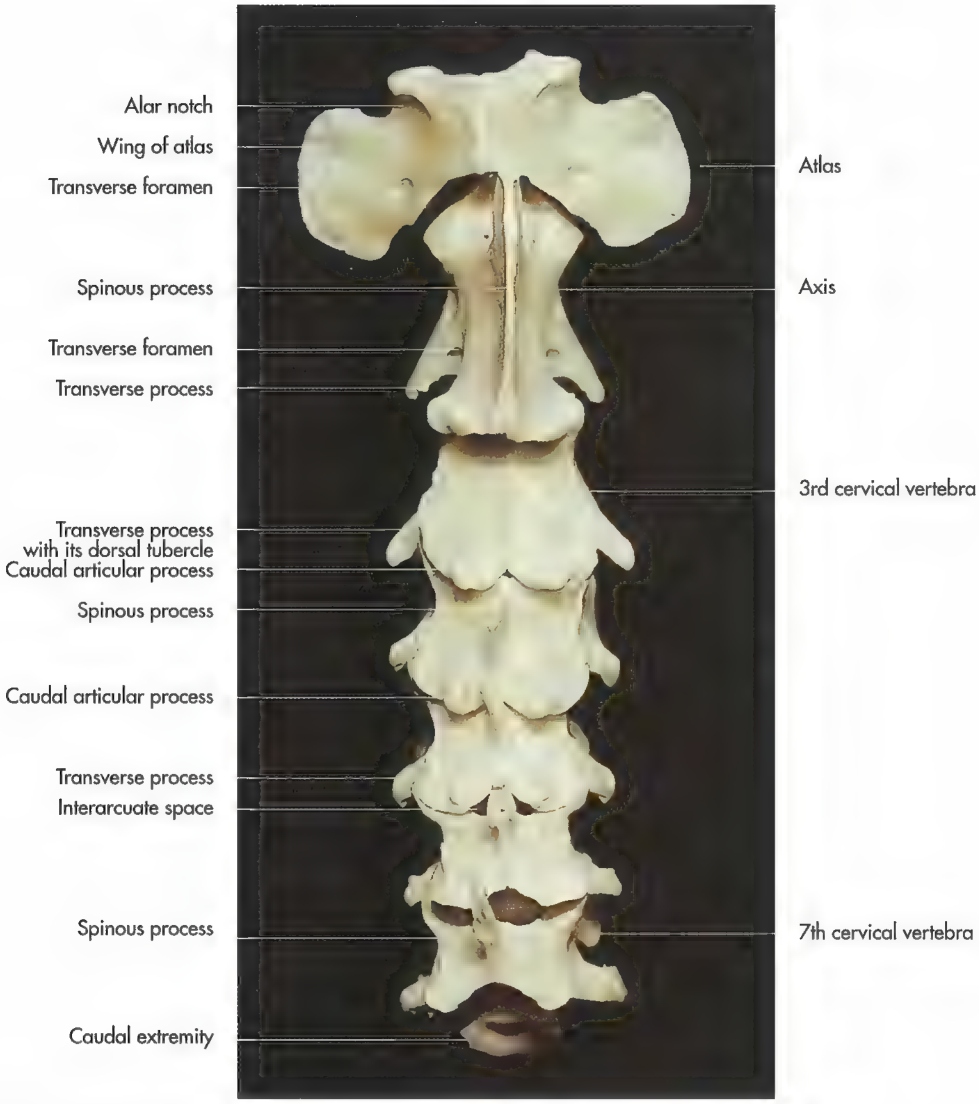

Fig. 1-79. Cervical spine of a dog (dorsal aspect).

The paired **transverse processes** (processus transversi) are perforated toward their base by the **transverse foramen** (foramen transversarium). The **cranial vertebral notch** (incisura vertebralis cranialis), present in carnivores is replaced by a **lateral vertebral foramen** (foramen vertebrale laterale) in the other domestic mammals, completed by a narrow bony bridge. Like the atlas the axis is modelled according to its functions. The dens of the axis forms together with the corresponding articular fovea of the atlas, a pivot joint around which the atlas and the head rotate. The articular surface on each side of the spinous process form the insertion of ligaments (especially the nuchal ligament) and muscles.

The bodies of the remaining cervical vertebrae become progressively shorter from cranial to caudal. The ventral surfaces of the third to fifth cervical vertebra carry a stout ventral crest, which becomes indistinct or is absent in the sixth and seventh vertebra, (Fig. 1-77 to 79). The cranial extremity is convex and the caudal extremity correspondingly concave, except in carnivores and the pig.

The **spinous processes** (processus spinosi) are comparatively short in most domestic mammals, but gradually increase in length towards the thoracic part of the spine. In the horse, only the seventh cervical vertebra possesses a distinct spinous process.

The transverse and articular processes are well-developed in all cervical vertebrae. On the third to sixth cervical vertebrae the transverse process is perforated by the **transverse foramen** (foramen transversarium). The summation of the transverse foramen forms a **transverse canal** (canalis transversarius) on either side of the cervical vertebral column, which transmits the vertebral nerve, artery and vein. The free end of each transverse process branches into a **dorsal tubercle** (tuberculum dorsale) caudally and a **ventral tubercle** (tuberculum ventrale) cranially, which are considered to be a rudimentary rib and the remnant of the transverse process of a thoracic vertebra. The ventral tubercle of the sixth cervical vertebra is enlarged to form a characteristic **plate-like extension** (lamina ventralis).

Fig. 1-80. Thoracic vertebra of a pig (left lateral aspect).

Fig. 1-81. Thoracic vertebra of an ox (craniolateral aspect).

The **articular processes** (processus articulares) are large, horizontally orientated and carry flat articular surfaces. The cranial and caudal ends of the vertebral arches are deeply notched on both sides (incisura vertebrales craniales et caudales), thus forming large intervertebral foramen (foramina intervertebralia) between adjacent vertebrae. The seventh cervical vertebra is easily distinguished from the others. It is characterised by a high spinous process and small transverse processes, the absence of a ventral crest (with the exception of the dog) and a transverse foramen. The caudal extremity of the vertebral body presents paired **articular fovea** (fovea costalis caudalis), which form a common articular surface for the head of the first rib together with the cranial articular surface of the first thoracic vertebra.

Thoracic vertebrae (vertebrae thoracicae)

The **thoracic spine** is composed of a chain of thoracic vertebrae. They form, partly overlapping, a slightly dorsoconvex bony rod, which is characterised by its limited flexibility. Adapted to their function the thoracic vertebrae are equipped with special anatomical features: the long spinous processes for the attachment of the strong head and neck musculature in pigs and herbivores. The cranial thoracic vertebrae fulfil an additional function as part of the entire vertebral column by transmitting the body weight to the thoracic limbs and, together with the ribs to provide attachment to the muscles of the ribs, thorax and shoulder.

The thoracic vertebrae articulate with the ribs and correspond with these in number. Minor numeric variations are common among different species and breeds and are often compensated for by reciprocal changes in the number of the lumbar vertebrae. All thoracic verebrae share the following common features (Fig. 1-80 to 86):

- Short bodies with flattened extremities (extremitates),
- Short articular processes (processus articulares),
- Closely fitting vertebral arches (arcus vertebrae),
- Very long spinous processes (processus spinosi),
- Costal facets on both extremities for the rib heads (foveae costales) and on the transverse processes for the rib tubercles.

The **vertebral bodies** are short in the cranial thoracic region, but gradually increase in length further caudal, where a ventral crest is also present. The cranial and caudal extremities of the caudal thoracic vertebrae are flattened conform to the intervertebral discs, which leads to a limited range of movement between two neighbouring vertebrae. The **articular processes** of the cranial thoracic vertebrae are represented by oval facets. The **cranial facets** (foveae articulares craniales) are situated craniodorsal on the base of the spinous process and are orientated tangentially to the vertebral arch. The **caudal facets** (foveae articulares caudales) are on the caudal aspect of the base of the spinous process, but orientate sagittally towards the arch. This arrangement of the articular facets is responsible for the relatively free rotational movement of the cranial thoracic region compared to the restriction of dorso-ventral movements of the caudal thoracic and lumbar region.

While the **cranial vertebral notch** (incisura vertebrales craniales) is shallow, the **caudal notch** (incisura vertebrales caudales) is much deeper. The **intervertebral foramen** is compara-

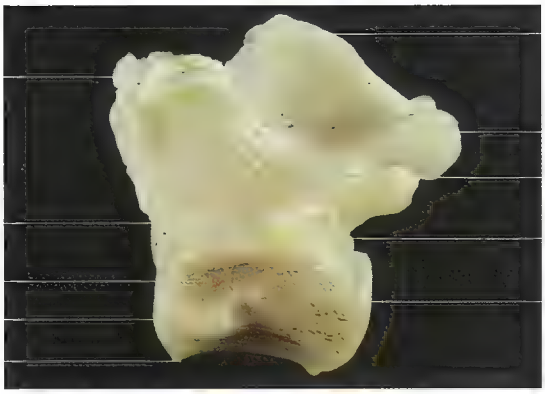

Fig. 1-82. 13th thoracic vertebra of a dog (lateral aspect).

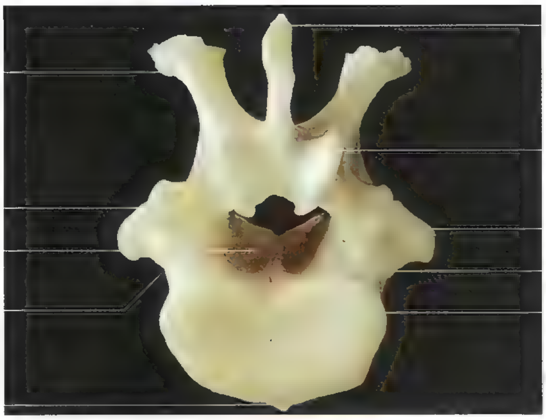

Fig. 1-83. 13th thoracic vertebra of a dog (caudal aspect).

Fig. 1-84. 13th thoracic vertebra of a pig (lateral aspect).

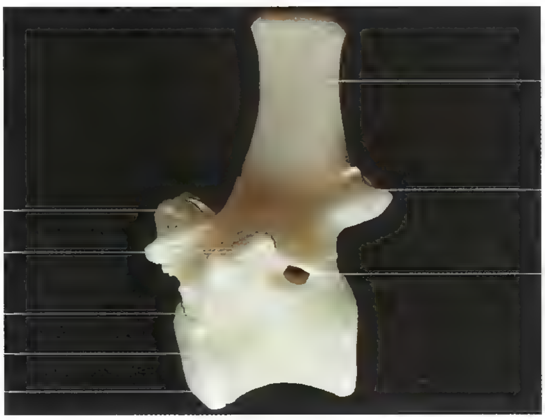

Fig. 1-85. 13th thoracic vertebra of an ox (lateral aspect).

Fig. 1-86. Radiograph of the thoracic spine of a dog (laterolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Fig. 1-87. Radiograph of the thoracic-lumbar region of the spine of a dog (laterolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

tively large to allow passage of the spinal nerves and vessels. It is often divided into two by a bony bridge in ruminants.

The **spinous processes** (processus spinosi) are very prominent and extend from the dorsal surface of the vertebral arch (Fig. 1-80 and 81). In carnivores, the spinous processes gradually decrease in length throughout the whole thoracic region; in the pig and ruminants they increase in height in the first three vertebrae, become progressively shorter up to the 11th vertebra in the pig and 12th or 13th in ruminants and stay at the same length for the remainder of the thoracic spine. In the horse, the spinous processes of the first four thoracic vertebrae increase in height and become shorter up to the 13th or 14th vertebra. The high spinous processes of the first three or four thoracic vertebrae constitute the osseous base for the withers (Fig. 1-86).

The spinous processes of the cranial thoracic vertebrae are directed caudodorsally, whereas the caudal thoracic and the lumbar vertebrae are inclined cranially (Fig. 1-82 and 85). The thoracic vertebra whose spinous process are nearly perpendicular to the long axis of that bone is termed the **diaphragmatic** or **anticlinal vertebra** (vertebra anticlinalis): it is the 10th thoracic vertebra in the dog (Fig. 1-87), the 12th in the pig and goat, the 13th in the ox and the 16th in the horse. The **mamillary processes** (processus mamillares) are only present in the thoracic and lumbar vertebrae. They are located just cranial to the transverse processes in those vertebrae located cranial to the anticlinal vertebra, and are fused with the articular processes to form the combined **mamilloarticular processes** (processus mamilloarticulares) in those vertebrae caudal to the anticlinal vertebra.

Fig. 1-88. Lumbar vertebra of an ox (dorsal aspect).

Fig. 1-89. Lumbar vertebra of an ox (cranial aspect).

Fig. 1-90. Fifth lumbar vertebra of a horse (dorsal aspect).

The body of each thoracic vertebra possesses a **cranial** and **caudal costal facet** (fovea costalis cranialis and caudalis) lateral to the base of the vertebral arch. The facets of adjacent vertebrae, complemented by the intervertebral discs, form sockets for the heads of the ribs. The short, stout **transverse processes** (processus transversi) present **articular facets** for the articulation with the costal tubercle (foveae costales processus transversi). The two costal facets are deeper and located further apart in the cranial thoracic region, but grow shallower and progressively closer, thus resulting in a higher stability of the cranial ribs, but an increased mobility caudally.

Lumbar vertebrae (vertebrae lumbales)

The **lumbar vertebrae** differ from the thoracic vertebrae in that they are longer and have a more uniform shape to their bodies (Fig. 1-88 to 94). The costal facets are absent, the spinous processes are shorter and directed craniodorsally, the transverse processes are long, flattened and project far laterally. The cranial and caudal extremities (extremitates craniales et caudales) of the bodies present flat articular surfaces. The vertebral arches form a widened vertebral canal to accommodate the swelling of the spinal cord in the

Fig. 1-91. Lumbar spine of a dog (lateral aspect).

Fig. 1-92. Radiograph of the lumbar spine of a dog (laterolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

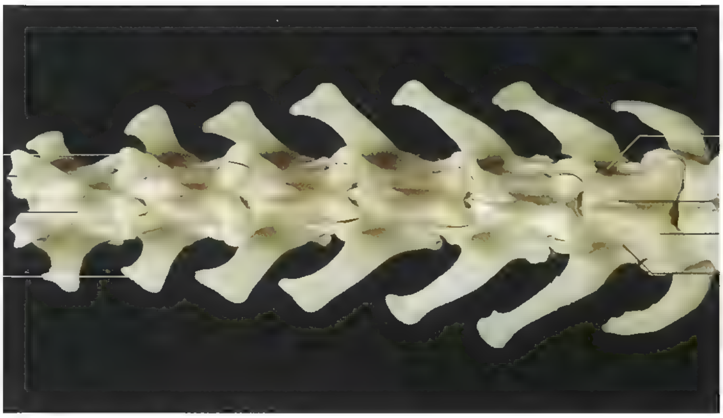

Fig. 1-93. Lumbar spine of a dog (dorsal aspect).

lumbar region, the **caudal intumescence** (intumescentia lumbalis).

The **spinous processes** are usually about equal in height and inclined cranially. In carnivores the first four or five lumbar vertebrae become progressively longer. In the ox, they show a caudal inclination, whereas in small ruminants they are orientated perpendicular to the long axis of the vertebrae.

The expanded **transverse processes** are the characteristic feature of the lumbar vertebrae. They represent rudimentary ribs and are therefore called **costal processes** (processus costales). In carnivores and the pig they have a cranioventral inclination, while in ruminants and the horse they are orientated horizontally, (Fig. 1-88 to 94).

The **first lumbar vertebra** has the shortest transverse processes and reach their maximum length usually in the third or fourth vertebrae in most domestic mammals, except in carnivores in which the fifth or sixth lumbar vertebra carries the longest transverse process. In the horse, the transverse processes of the last two lumbar vertebrae and those of the last lumbar and first sacral vertebrae articulate with each other. This results into the division of the intervertebral fora-

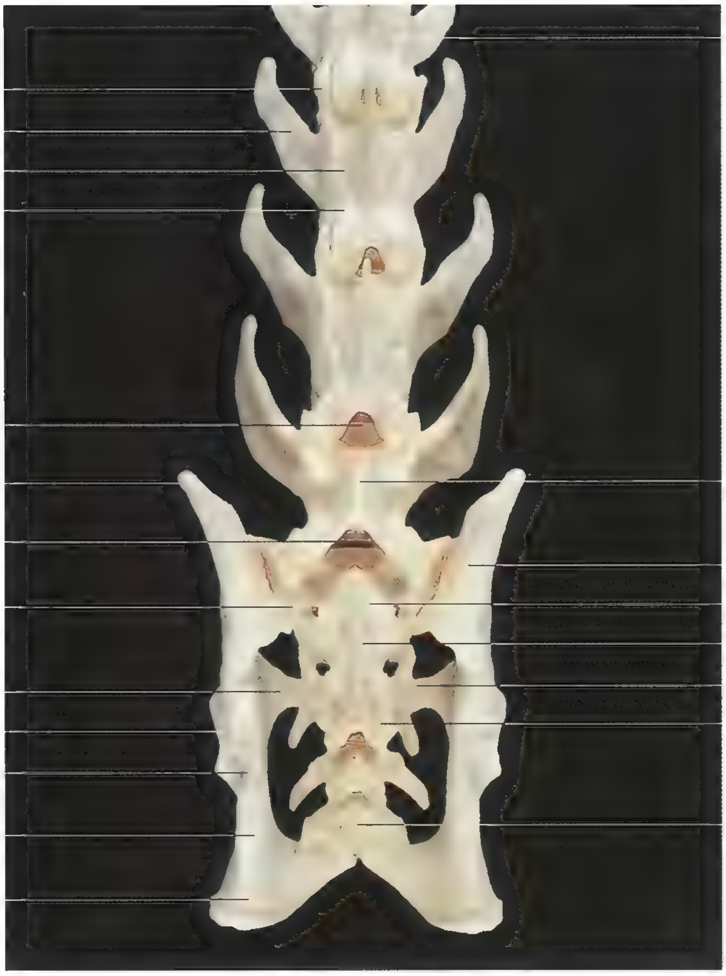

Fig. 1-94. Last lumbar vertebrae, sacrum and pelvis of a cat (dorsal aspect).

men in a dorsal and a ventral opening. The **transverse** and **spinous processes** as well as the distinct ventral crest provide large surfaces for the attachment of the inner lumbar muscles and the abdominal, axial and pelvic musculature.

The sagittal orientation of the **articular processes** permits only movement in a ventral and dorsal direction and lateral movements are nearly impossible. The articular processes fuse with the mamillary processes to form the club-shaped **mamilloarticular process.**

The **interarcuate spaces** (spatia interarcualia) are narrow in the lumbar region, but wide between the last lumbar and the first sacral vertebra, forming the **lumbosacral interarcuate space** (spatium interarcuale lumbosacrale), which can be used to access the vertebral canal. In the cat, the interarcuate space between the last two lumbar vertebrae is also wide enough to allow injections into the vertebral canal.

Os sacrum (vertebrae sacrales)

The **sacral vertebrae** and their ossified intervertebral discs are firmly fused to form a single bone, the sacrum, in all domestic species (Fig. 1-94 to 101). The fusion of the single elements is usually completed by 1.5 years of age in carnivores and the pig, 3–4 years in ruminants and 4–5 years in the horse. The ossification of the vertebral articulations results in a loss of flexibility of the sacral vertebral column. This increases the effectiveness of the transmission of the forward impetus in locomotion from the hindlimbs to the vertebral column.

The first sacral vertebra with its expanded wings forms a firm articulation with the pelvic girdle through which the thrust of the hindlimbs is transmitted to the trunk. The more caudal parts of the sacrum do not directly participate in this articulation, but constitute the major part of the roof of the pelvic cavity. The limited variety of function of the sacral vertebrae is reflected in the simplified architecture of the sacrum.

The **sacrum** (os sacrum) is quadrilateral in form in carnivores, but triangular in the other domestic mammals (Fig. 1-95 to 101). It is divided into an expanded **base** (basis ossis sacri) cranially, two **lateral parts** (partes laterales), enlarged by the **sacral wings** (alae ossis sacrae) and a **caudal extremity** (apex ossis sacri). Its **dorsal surface** (facies dorsalis) has spinous processes, which may be present only as remnants in some species, and various ridges. The ventral surface, which faces towards the **pelvic cavity** (facies pelvina) is marked by **transverse lines** (lineae transversae), which indicate the former limits of the individual vertebrae.

Fig. 1-95. Sacrum of a dog (dorsal aspect).

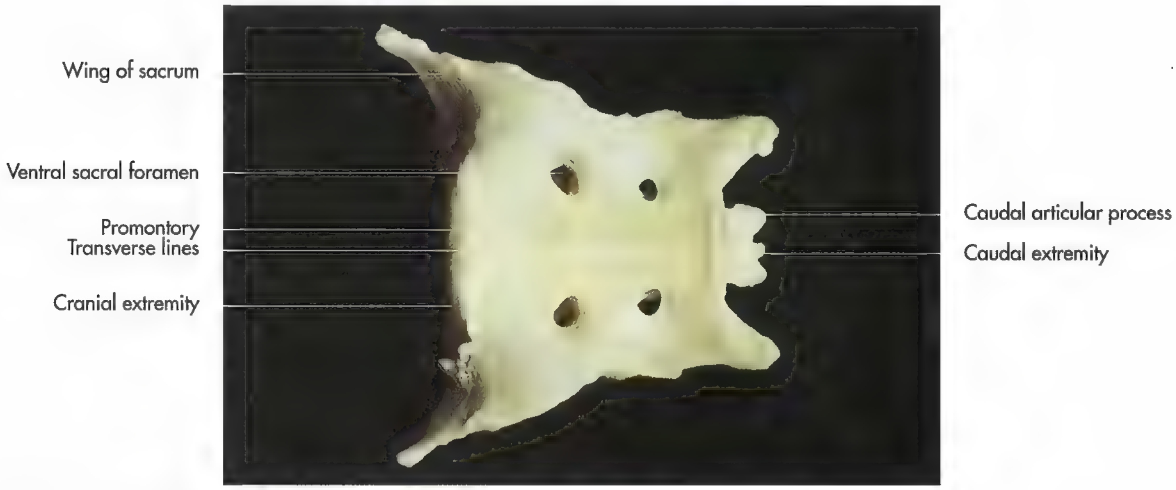

Fig. 1-96. Sacrum of a dog (ventral aspect).

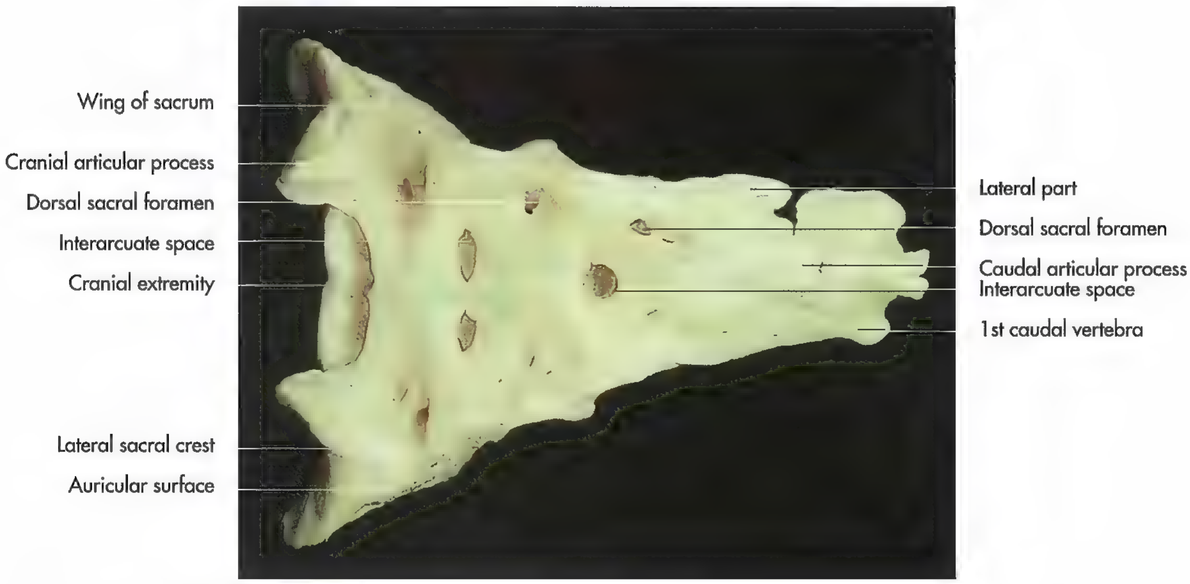

Fig. 1-97. Sacrum of an elderly pig (dorsal aspect).

Fig. 1-98. Sacrum of an ox (dorsal aspect).

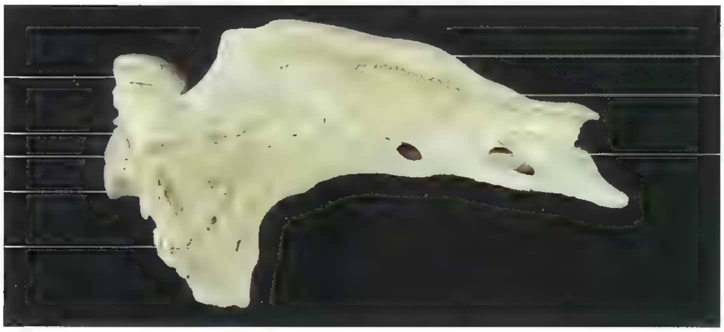

Fig. 1-99. Sacrum of an ox (lateral aspect).

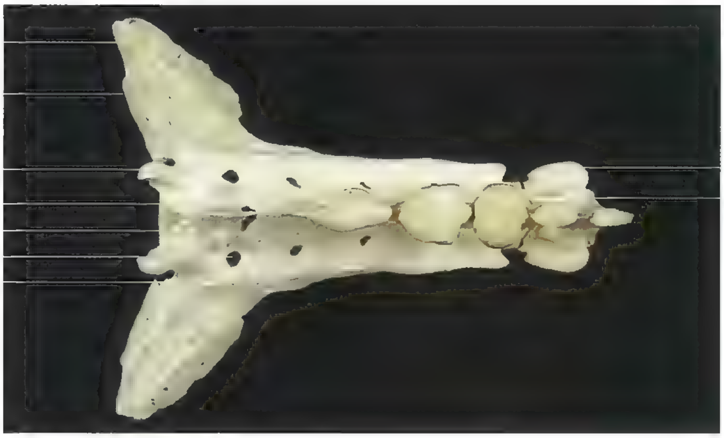

Fig. 1-100. Sacrum of a horse (dorsal aspect).

Fig. 1-101. Sacrum of a horse (lateral aspect).

Fig. 1-102. Fourth caudal vertebra of a dog (ventral aspect).

Fig. 1-103. Fifth caudal vertebra of a dog (cranial aspect).

The dorsal surface gives attachment to the hip, rump and hamstring musculature and provides openings for the passage of the dorsal spinal nerves of the **lumbosacral plexus** (plexus lumbosacralis). The ventral surface of the sacrum is smooth and slightly concave and is perforated by the openings for the ventral branches of the spinal nerves. The vertebral canal is much narrower in the sacral region (canalis sacralis) than in the lumbar region and its diameter diminishes even further to about half its size at the sacral apex.

The cranial extremity articulates with the last lumbar vertebra and is notched to form the **cranial vertebral notch** (incisura vertebralis cranialis). Its ventral margin extends a cranioventral projection, the **promontory** (promontorium), dorsally it presents cranial articular processes. The lateral parts are formed by the fused transverse processes of the sacral vertebrae and are enlarged by the expanded sacral wings, which project laterally and originate from the first sacral vertebra (Fig. 1-98 to 101). The second sacral vertebra contributes to the formation of the sacral wings in carnivores, pigs and small ruminants. On the dorsal surface of each wing is an oval area (facies auricularis), which is covered with cartilage, for the articulation with the wing of the ilium with which it forms a rigid joint. The dorsal margin of the sacral wing is roughened for the attachment of the sacroillial ligaments (tuberositas sacralis).

The dorsal surface carries the caudally inclined **spinous processes.** These differ widely in the domestic species (Fig. 1-95 and 99 to 101). In carnivores and the horse, the free ends of the spinous processes remain separate, while their bases are fused. In ruminants the dorsal spines are fused to form the **median sacral crest** (crista sacralis mediana). In the pig the spinous processes are replaced by an indistinct crest.

The transverse processes are united to form a **lateral sacral crest** (crista sacralis lateralis), which is distinct in the pig and horse, but insignificant in the other domestic mammals. An **intermediate sacral crest** (crista sacralis intermedia) is found in ruminants and represents the fused rudiments of the articular processes. In the other domestic mammals this crest is replaced by small tubercles. The nerves of the lumbosacral plexus leave the vertebral canal through the ventral and dorsal sacral foramina (foramina sacralia ventralia et dorsalia).

Caudal or coccygeal vertebrae (vertebrae caudales)

The **caudal vertebrae** gradually reduce in size from first to last. They also show a progressive simplification in their form by losing characteristic vertebral features, such as arches and processes. The last caudal vertebrae resemble cylindrical rods of diminishing size.

The cranial members of the caudal spine conform most typically to the common anatomical architecture of the representative vertebra, but the more caudal ones are gradually reduced to simple rods, by losing the characteristic features, notably the processes. In the horse the spinous processes of the second caudal vertebra is bifurcated and the arch of the third caudal vertebra is already incomplete, thus the vertebral canal is open dorsally. The transverse processes are reduced to small elevations and from the seventh caudal vertebra onwards all processes are missing, their former position only marked by small bony ridges.

For the protection of the caudal (coccygeal) vessels the ventral surface of a few caudal vertebrae (first to 8th caudal vertebra in ruminants, 5th to 15th caudal vertebra in carnivores) show paramedian processes, the **hemal processes** (processus hemales). These hemal processes form **ventral arches** (arcus hemalis) on certain caudal vertebrae (second and third in the ox, third to 8th in carnivores). The interarcuate spaces between the sacrum and the first caudal vertebra and between the first few caudal vertebrae are widened and provide access to the vertebral canal.

Thoracic skeleton (skeleton thoracis)

The **thoracic skeleton** comprises the **thoracic vertebrae** (vertebrae thoracicae), the **ribs** (costae) and the **sternum** (Fig. 1-104). The thorax encloses the **thoracic cavity** (cavum thoracis), which is accessible cranially through the cranial aperture or thoracic inlet between the first ribs (apertura thoracis cranialis). The caudal aperture (apertura thoracis caudalis) is framed on both sides by the costal arches. The thoracic wall is composed of the **costal arch** (arcus costalis), the **intercostal spaces** (spatia intercostalia) and the angle between the left and

Fig. 1-104. Skeleton of the thorax of a cat (lateral aspect).

right costal arches (angulus arcuum costalium). The bony thorax is compressed laterally in its cranial part and widens caudally in herbivores, but is stouter and deeper ventrally in carnivores.

Ribs (costae)

The **ribs** form the skeleton of the lateral thoracic walls. They are arranged serially in pairs and are interspersed by the intercostal spaces. Each rib consists of a bony dorsal part, the **osseous part** (os costale) (Fig. 1-105 to 108) and a cartilagenous ventral part, the **costal cartilage** (cartilago costalis) (Fig. 1-104), which meet in the **costochondral junction.**

The dorsal parts of all ribs articulate with the thoracic vertebrae, while the costal cartilages differ in their articulation with the sternum. The first seven to nine ribs articulate directly with the sternum and are therefore termed **sternal** or **"true ribs"** (costae verae seu sternales). The remaining caudal ribs articulate indirectly with the sternum by uniting with the cartilage of the rib in front to form the costal arch. These ribs are called **asternal** or **"false ribs"** (costae spuriae seu asternales). Ribs at the end of the series, whose cartilage ends free in the musculature without attachment to an adjacent cartilage are named **"floating ribs"** (costae fluctuantes). In the dog and cat the last pair of ribs are always floating.

The pair of ribs correspond in number to the thoracic vertebrae. Accordingly carnivores possess 12 to 14 pairs of ribs, the pig 13 to 16, ruminants 13 and the horse 18. The ratio of sternal to asternal ribs is 9:4 in carnivores, 7:7 (8) in the pig, 8:5 in ruminants and 8:10 in the horse, but may vary with the number of the thoracic vertebrae.

All ribs share a common basic architecture (Fig. 1-105 to 109) and consist of:

- **Head** (caput costae) with its articulating surfaces (facies articulares capitis costae),
- **Neck** (collum costae),
- **Tubercle** (tuberculum costae) with its articulating surface (facies articularis tuberculi costae),
- **Body** or **shaft** (corpus costae) and
- **Sternal extremity.**

The vertebral extremity carries a rounded **head** (caput costae), that has a cranial and a caudal facet (facies articularis capitis costae) for the articulation with the socket, formed by the cranial and caudal costal fovea on the bodies of two adjacent vertebrae. The two articulating surfaces are separated by a groove for the attachment of the intraarticular ligament of the head of the rib. The head is joined to the costal body by a distinct **neck** (collum costae), which carries a **tubercle** (tuberculum costae) at the junction of the body. The costal tubercle bears a facet (facies articularis tuberculi costae) for articulation with the transverse process of the same vertebra. Since the necks of the ribs become gradually shorter caudally (except in the ox), the articular facets of the head and the tubercle grow closer until they become confluent. This results in an increased movability of the

Fig. 1-105. Rib of a dog (caudal aspect).

Fig. 1-106. Rib of a pig (caudal aspect).

Fig. 1-107. Rib of an ox (caudal aspect).

Fig. 1-108. Rib of a horse (caudal aspect).

last few pairs of ribs. The **body** or **shaft** of the rib is distal to the costal tubercle (corpus costae). The region where the costal body is most strongly bent is termed the **costal angle** (angulus costae). Its surfaces and borders provide attachment to the muscles of the trunk, especially to the respiratory musculature. Its caudal margin is grooved (sulci costae) to give protection to the intercostal vessels and the spinal nerves.

The shape and size of the costal bodies vary greatly in the different species (Fig. 1-105 to 109). The ribs of the dog are more curved than the ribs of the other domestic mammals. The length of the ribs gradually increases in the first 10 ribs to become progressively shorter caudal to it. The cranial surface is flattened, the caudal one rounded. In the pig the second to fourth costal bodies are conspicuously broad and flat, becoming more slender caudally. The costal cartilage of the first rib is very short and joins the corresponding cartilage of the other side to form a common articulating surface towards the sternum. The ribs of ruminants are flat with sharply defined margins and expand towards the sternum. The first six or eight ribs are the widest, the seventh to tenth ribs the longest. In the horse the curvature of the ribs increases up to the 11th rib. The ribs caudal to the 11th are less curved but show an increase in angulation. While the width gradually decreases from cranial to caudal, the thickness increases.

The distal end of the body unites with the **costal cartilage** (cartilago costalis) forming a **symphysis,** the costochondral junction. The ribs are steeply angled to the sternum at the level of the **costochondral junction** (genu costae). In carnivores this angle is formed only by the costal cartilages. The cylindrical end of the costal cartilage of the sternal ribs articulate with the sternum. Each pair of ribs joins the sternum between successive sternal segments (Fig. 1-104), with the exception

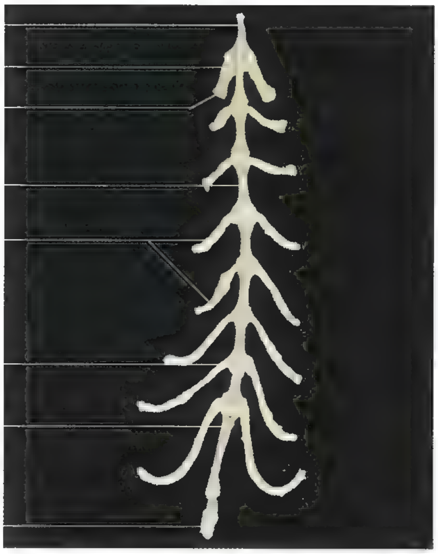

Fig. 1-109. Sternum of a cat (dorsal aspect).

Fig. 1-110. Sternum of a horse (ventral aspect).

Fig. 1-111. Sternum of a horse (lateral aspect).

of the first pair which articulates with the first sternebra (manubrium sterni). The costal cartilages of the asternal ribs are attached to their neighbours by connective tissue to form the costal arch. The articulation of the costal arches of each side form an angle, into which the **xiphoid cartilage** projects.

Sternum

The **sternum** consists of an unpaired, segmental series of bones (sternebrae) which are joined together by the **intersternal cartilages** (synchondroses sternales). The individual segments fuse, with ossification of the intersternal cartilage in older animals (Fig. 1-109 to 111). The sternum can be divided into three parts:

- **Manubrium** (manubrium sterni),
- **Body** (corpus sterni) and
- **Xiphoid process** (processus xiphoideus).

The **manubrium** constitutes the most cranial part of the sternum and projects in front of the second intercostal junction. Since the **clavicle** is rudimentary in all domestic mammals, the manubrium is poorly developed in all of these species. It carries the articular facets for the first pair of ribs and may be palpated at the root of the neck in some animals. Its cranial end is prolonged by **cartilage** (cartilago manubrii), which has the shape of a short, blunt cylinder in carnivores, while it is a long, dorsally convex and laterally compressed projection in

the horse. In ruminants this cartilage is represented by a thin layer only or missing altogether.

The **body of the sternum** (corpus sterni) is cylindrical in carnivores, wide and flat in ruminants and carries a **ventral keel** in the horse (crista sterni) (Fig. 1-109 to 111). It is composed of four to six segments, depending on the species (dog 8-9, ruminant and horse 7 (the horse sometimes 8), pig 6). It is a uniform cylinder in cats, but in the dog it is rectangular, being higher than it is wide. In ruminants and the pig it is dorsoventrally compressed, whereas in the horse it is laterally compressed and extended ventrally. The dorsolateral margin is marked by a series of notches (incisurae costales), which receive the costal cartilages of the sternal ribs for articulation. The more caudal of these depressions are situated closely together and may articulate with more than one costal cartilage at a time.

The **xiphoid process** (processus xiphoideus) is the last sternebra, which extends into a **cartilagenous process** (cartilago xiphoidea) caudally. It projects between the ventral parts of the costal arches (regio xiphoidea). While the xiphoid cartilage is broad and expanded in ruminants and horses, it is thin and narrow in the other domestic mammals. It supports the cranial part of the ventral abdominal wall and forms the attachment to the linea alba.

Joints of the skull and trunk (suturae capitis, articulationes columnae vertebralis et thoracis)

Joints of the skull (synchondrosis cranii)

In young animals the bones of the skull are united by **cartilagenous junctions** (synchondroses), which ossify with advanced age to form **osseous sutures** (suturae capitis). Some of the articulations at the base of the skull remain cartilagenous and are therefore radiographically visible throughout life and are termed by the names of the bone, which participate in their formation (e.g. synchondrosis sphenooccipitalis, synchondrosis sphenopetrosa, synchondrosis intersphenoidalis, synchondrosis petrooccipitalis). The majority of the junctions ossify resulting in immobile articulations. In some canine breeds the frontal, parietal and occipital bones stay separated forming permanent fontanelles.

Apart from the above described sutures there are three other joints of the head:

- **Intermandibular joint** (articulatio intermandibularis),
- **Temporohyoid joint** (articulatio temporohyoidea) and
- **Temporomandibular joint** (articulatio temporomandibularis).

The **intermandibular joint** is the median osseous junction, uniting the right and left mandibular bodies (sutura intermandibularis), which takes the form of a synostosis in the pig and horse. A small articular area remains cartilagenous, forming a synchondrosis.

The **temporohyoid joint** joins the suspensory part of the hyoid apparatus, which is composed of the epihyoid, stylohyoid and tympanohyoid to the base of the skull. The tympanohyoid articulates with the styloid process in ruminants and the horse, the mastoid process in carnivores and the nuchal process of the temporal bone in the pig forming a syndesmosis or synchondrosis respectively. The articulations between the individual parts of the hyoid apparatus are described earlier in this chapter.

The **temporomandibular joint** is the synovial joint between the mandibular ramus and the squamous part of the temporal bone. It is a condylar joint (articulatio condylaris), whose articulating surfaces do not entirely correspond to each other. To compensate for this incongruency a **fibrocartilagenous disc** (discus articularis) is interposed between the articulating surfaces.

The temporomandibular joint is formed by the head of the condyloid process of the mandible (caput mandibulae) and the **articular area of the temporal bone,** which consists of the articular tubercle rostrally, the **mandibular fossa** (fossa mandibularis) with its transverse articular surface in the middle and the **retroarticular process** (processus retroarticularis) caudally. The joint capsule extends from the free margins of the articular surfaces and attaches to the entire edge of the disc. Thus the joint cavitiy is completely divided into a larger dorsal and a smaller ventral compartment by the inner synovial layer (membrana synovialis) of the joint capsule. The outer fibrous layer of the joint capsule (membrana fibrosa) is strengthened by the tight **lateral** (ligamentum laterale) and the **caudal ligaments** (ligamentum caudale), which extend between the retroarticular process and the base of the coronoid process. The caudal ligament is not present in carnivores and the pig. The main movements of the temporomandibular joint are up and down, to open and close the mouth. A limited degree of lateral grinding and forward and backward movements of the manbible are also possible. The species specific variations are based on the pattern of mastication and are influenced by the masticatory muscles.

Joints of the vertebral column, the thorax and the skull (articulationes columnae vertebralis, thoracis et cranii)

The articulations between the vertebrae, the thorax and the skull can be grouped into:

- Articulations between the skull and the vertebral column,
- Atlantooccipital joint (articulatio atlantooccipitalis) between the skull and the first cervical vertebra,
- Atlantoaxial joint (articulatio atlantoaxialis) between the first and second cervical vertebra,
- Articulations between adjacent vertebrae (symphysis intervertebralis),
- Articulations between the thoracic vertebrae and the ribs (articulationes costovertebrales),
- Articulations between the head of the ribs with the appropriate vertebra (articulationes capitis costae),

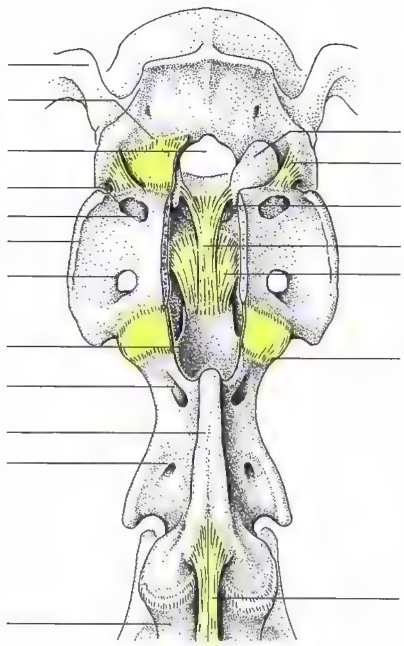

Fig. 1-112. Ligaments and joint capsule of the atlantooccipital and atlantoaxial joints of the horse (schematic, dorsal aspect) (Ellenberger and Baum, 1943).

- Articulations between the tubercle of the ribs and the appropriate vertebrae (articulationes costotransversaria),
- Articulations of the thorax (articulationes thoracis) Articulations between the sternum and the costal cartilages (articulationes sternocostales),
- Articulations between the ribs and the costal cartilages (articulationes costochondrales),
- Articulations between the costal cartilages (articulationes intrachondrales) and
- Articulations between the individual sternebrae (synchondroses sternales).

The joints between the skull and the vertebral column are responsible for the movement of the head. They comprise the cranial **atlanto-occipital joint** between the occiput and the first cervical vertebra and the **atlantoaxial joint** between the first and the second cervical vertebra (Fig. 1-112). The movements of these two joints have to be considered together, since they form a functional unit between the skull and the rest of the vertebral column.

The **atlanto-occipital joint** is composed of **two ellipsoidal joints** (articulationes ellipsoideae) formed between the **occipital condyles** (condyli occipitales) and the **corresponding concavities of the atlas** (foveae articulares craniales) (Fig. 1-112 to 114). Each joint has its own joint capsule (capsula articularis) which attaches around the articular surfaces. The two joint cavities remain separated dorsally, but communicate ventrally in carnivores and ruminants and in the aged pig and horse. In carnivores the atlantooccipital joint shares a common joint cavity with the atlantoaxial joint.

Several ligaments (ligamenta articularia) support this joint functionally: **lateral ligaments** bridge the joint space between the medial aspect of the paracondylar processes of the occiput and the root of the **wing of the atlas** (alae atlantis). The dorsal and ventral side of the joint capsule is reinforced by individual, expansive sheets of fibrous tissue, the dorsal and ventral atlanto-occipital membranes (membranae atlantooccipitalis dorsalis et ventralis). They cover the extensive joint space between the occiput and the atlas (spatium atlantooccipitale). The shape of the articular surface restricts movement between the atlas and the skull to flexion and extension in the sagittal plane only.

The **atlantoaxial joint** is a **trochoid** or **pivot joint** (articulatio trochoidea) formed by the **dens of the axis** and the corresponding **cavity** (fovea dentis) of the atlas (Fig. 1-112). The articulating surface is enlarged by the **caudal articular facets** (foveae articulares caudales) of the atlas and the **cranial articular facets of the axis** (foveae articulares craniales). All articulations are enclosed in a common joint capsule, thus forming a single synovial cavity. The peculiar anatomy of the articular surfaces allows rotational movements along the longitudinal axis of the dens. Ligaments brace the joint in a species-specific way.

The joint capsule is strengthened externally by the **dorsal atlantoaxial membrane** (membrana atlantoaxialis dorsalis) extending between the vertebral arches of the first and second cervical vertebra. The **elastic dorsal axial ligament** (ligamentum atlantoaxiale dorsale) extends between the dorsal tubercle of the atlas and the spinous processes of the axis. The dens of the axis is secured by additional ligaments (ligamenta alaria), which arise from the dens and attach to the inner surface of the ventral arch of the atlas in ruminants and the

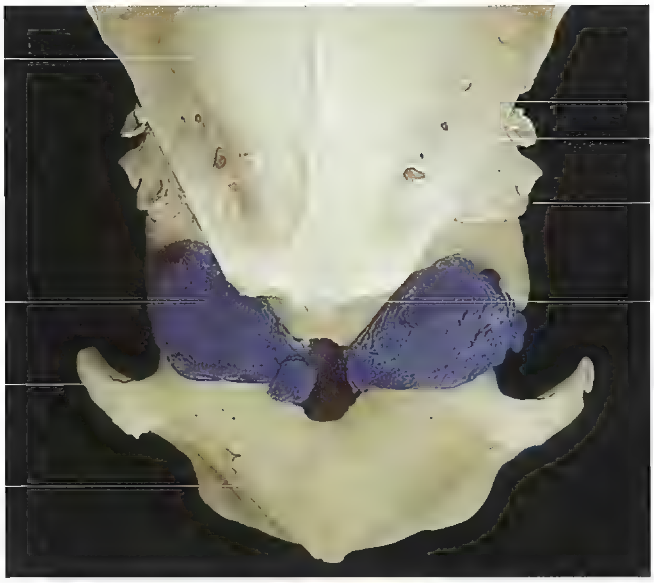

Fig. 1-113. Equine skull with acrylic cast of the atlantooccipital joint (dorsal aspect).

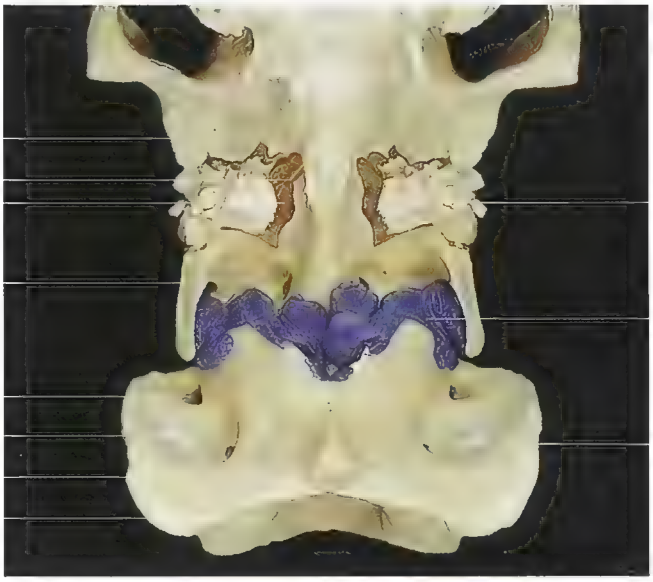

Fig. 1-114. Equine skull with acrylic cast of the atlantooccipital joint (ventral aspect).

horse, to the medial surface of the condyles in carnivores and to the rim of the foramen magnum in the pig.

In ruminants and the horse, the joint capsule is reinforced ventrally by the **ventral atlantoaxial ligament** (ligamentum atlantoaxiale ventrale), extending between the ventral tubercle of the atlas and the ventral spine of the axis. In the same domestic species the vertebral canal contains the longitudinal ligaments which fan out from the dorsal surface of the dens to insert on the basilar part of the occiput and the occipital condyles.

In pigs and carnivores the **transverse ligament of the atlas** (ligamentum transversum atlantis) straps the dens to the atlas. This prevents undue movement of the dens in relation to the vertebral canal and at the same time protects the medulla oblongata from fatal mechanical insults.

Intervertebral articulations (articulationes columnae vertebralis)

The **vertebral column** with its multicomposite structure (soft tissue, cartilagenous and osseous tissue) has to fulfil a variety of functions. Two adjacent vertebrae with the interposed cartilagenous disc, the articulations between them and the bracing ligaments form a **functional unit,** which is responsible for conveying the thrust from the limbs to the body during locomotion. These functional units are complemented by the nerves and blood vessels leaving the vertebral canal through the intervertebral foramina and the covering muscles of the cervical, thoracic, lumbar and sacral region. The **intervertebral articulations** (articulationes columnae vertebralis) combine symphyses between the vertebral bodies (symphyses in-

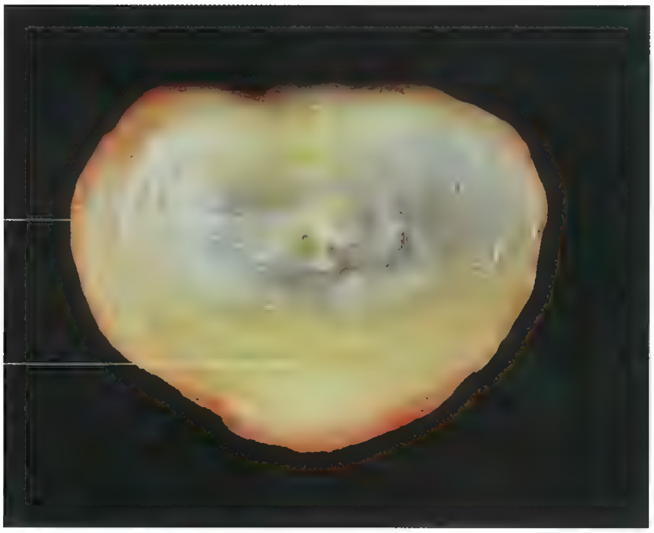

Fig. 1-115. Lumbar intervertebral disc of a dog.

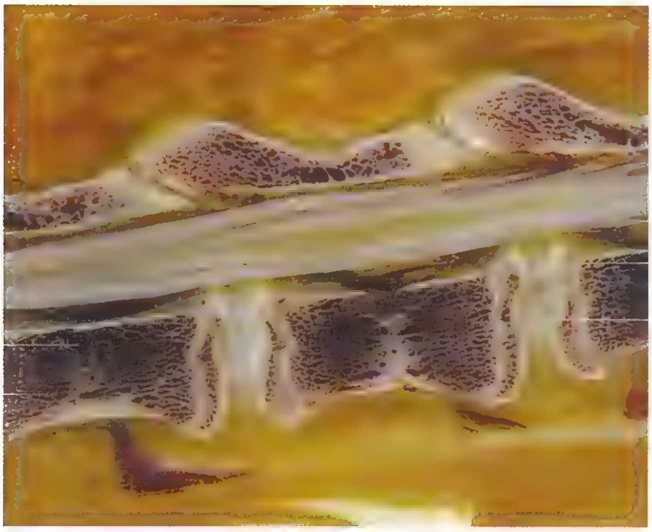

Fig. 1-116. Lumbar intervertebral discs of a dog (median section).

tervertebrales) and synovial joints between the articular surfaces (articulationes processuum articularium). The **cranial** and **caudal extremities** (extremitates craniales et caudales) of two adjacent vertebra are connected by **intervertebral discs** (disci intervertebrales) (Fig. 1-115 and 116). The articulations between the cranial and caudal articular facets of the vertebrae are **plane joints** (articulationes planae). The individual vertebrae are linked together by short and long ligaments as well as the continuous nuchal ligament, except in cats and pigs, and the supraspinous ligament in all species. These ligaments are described in detail later.

The form and length of the intervertebral discs make an appreciable contribution to the structure and shape of the whole column. The thickness of the discs decreases throughout the thoracic and lumbar region to reach their minimum thickness within the lumbar column. The cervical intervertebral discs are thinner dorsally than ventrally.

Each intervertebral disc consists of two parts, the **pulpy nucleus** (nucleus pulposus) and the **fibrous ring** (anulus fibrosus) (Fig. 1-115 and 116). The latter is covered by fibrous tissue. While juvenile intervertebral discs are supplied by blood vessels, these vessels degenerate in later life and the discs are nourished by diffusion from adjacent tissues (bradytrophic tissue). The encircling fiber bundles of the fibrous ring (anulus fibrosus) pass obliquely from one vertebra to the other, merging with the cartilage that cover the vertebral extremities (synchondrosis).

The fibers are arranged in several spiral layers (laminae) orientating around the longitudinal axis of the vertebrae and change their orientation between successive laminae. This

Fig. 1-117. Nuchal and supraspinous ligament of a dog (lateral aspect).

anatomical arrangement results in stability of the intervertebral disc and a reduced mobility between adjacent vertebrae.

The mean thickness of the discs of the equine thoracic vertebrae measures between 2 to 3 mm, with the exception of the disc between the first and second thoracic vertebra, which is double in thickness than the successive vertebrae. The pulpy nucleus is situated in the functional center of the axis of the vertebral column. It is maintained under pressure and spreads the compressive forces to which the vertebral column is subjected over a wider part of the vertebra. This results in a tensioning of the surrounding fibrous ring and the ventral and dorsal ligaments.

The thickness of the intervertebral disc is largely responsible for the flexibility of the spine. With advancing age, however, the discs tend to show degenerative changes. Most commonly the pulpy nucleus, which itself is under continous pressure, presses against the weakened fibrous ring, resulting in protrusion or herniation of the disc towards the vertebral canal. If the fibrous ring fragments, then the pulpy nucleus prolapses into the vertebral canal, where it may impinge upon the spinal cord or compress nerves and blood vessels.

Ligaments of the vertebral column

The ligaments of the vertebral column can be grouped into short ligaments, bridging successive vertebrae and long ligaments spanning several vertebrae forming functional units (Fig. 1-117 to 119).

Short ligaments:

- **Interarcuate ligaments** (ligamenta flava) are elastic sheets filling the interarcuate spaces. They help to support the weight of the trunk and the rump musculature and assist the back musculature.
- **Interspinous ligaments** (ligamenta interspinalia) extend between the spinous processes of the vertebrae. These are elastic ligaments in the cranial part of the equine spine and the caudal part of the bovine spine, but are muscular in the thoracic and lumbar spine of carnivores. They prevent the vertebrae from sliding dorsally and at the same time limit ventral flexion of the spine.
- **Intertransverse ligaments** (ligamenta intertransversaria) extend between the transverse processes of the lumbar vertebrae and are tensed during lateral flexion and rotation.

Long ligaments:

- **Dorsal longitudinal ligament** (ligamentum longitudinale dorsale) passes along the floor of the vertebral canal from the dens of the axis to the sacrum and is attached to each of the intervertebral discs.
- **Ventral longitudinal ligament** (ligamentum longitudinale ventrale) follows the ventral aspect of the vertebrae from the eighth thoracic vertebra to the sacrum and attaches to each of the intervertebral discs.

The **nuchal ligament** supports much of the weight of the head when the head is held high, thus relieving load from the head and neck musculature. The powerful development of this ligament and the nuchal musculature has induced an enlargment of the spinous processes of the thoracic vertebrae to which they attach. It arises from the axis in the dog and from the occiput in ruminants and the horse and continues caudally as the **supraspinous**

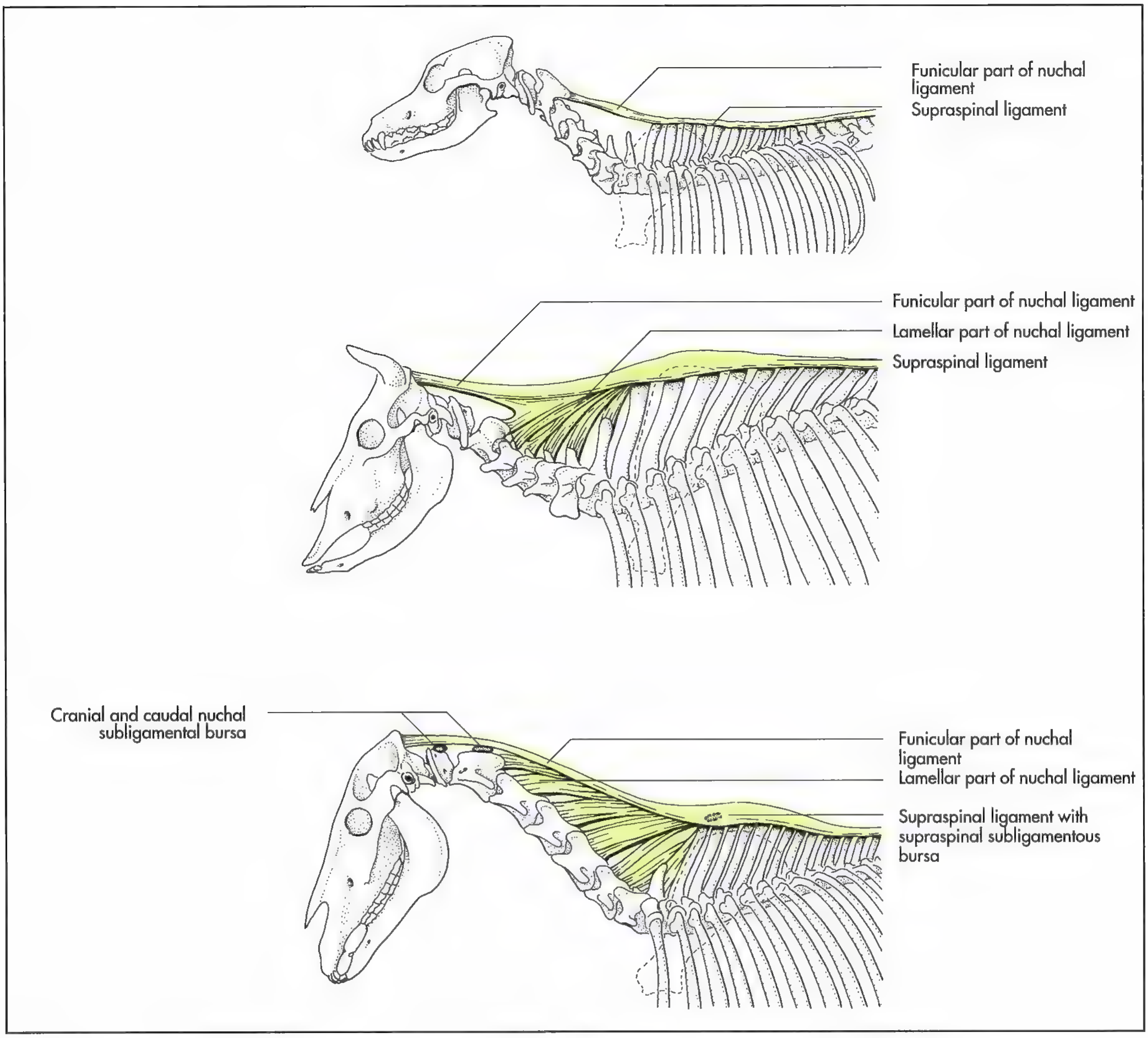

Fig. 1-118. Nuchal and supraspinous ligament of the dog, ox and horse (schematic, lateral aspect) (Ellenberger and Baum, 1943).

ligament (ligamentum supraspinale) (Fig. 1-117 and 118). The nuchal ligament is not present in the cat or the pig, however, these species do possess a supraspinous ligament.

The nuchal ligament (ligamentum nuchae) can be subdivided into:

- **Nuchal funiculus** (funiculus nuchae),
- **Nuchal lamina** (lamina nuchae).

In the dog the nuchal ligament is represented by the paired **funiculus nuchae,** which arises from the caudal aspect of the spinal process of the axis and inserts to the spinous process of the first thoracic vertebra from which it continues caudally as the supraspinous ligament. The supraspinous ligament attaches to the free ends of the spinal processes of the vertebrae up to the third sacral vertebra.

In ruminants the nuchal ligament consists of **two parts, the cord-like funiculus nuchae** and the **lamina nuchae.** The paired funiculus originates from the external occipital protuberances and fans out caudal to the axis to form a paired plate, which attaches to both sides of the spinous processes of the cranial thoracic vertebrae, thus forming the base of the withers. It continues caudally as the supraspinous ligament. The paired cranial part of the lamina nuchae arises from the spinous processes of the second to fourth cervical vertebrae and radiates into the funiculus nuchae ventrally. The caudal part is unpaired and extends from the spinous processes of the fifth to seventh cervical vertebrae under the funiculus nuchae to the spinous process of the first thoracic vertebra.

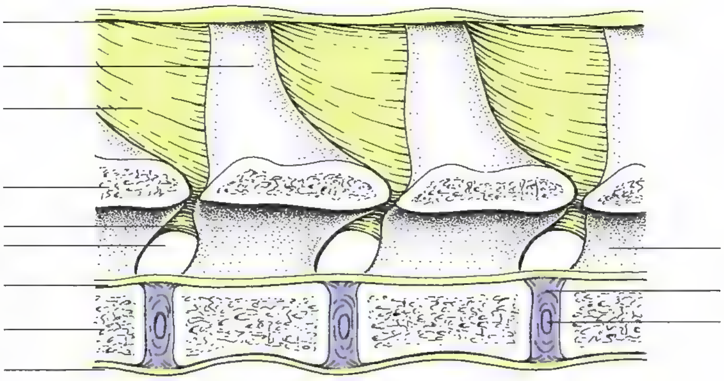

Fig. 1-119. Long and short ligaments of the lumbar spine (schematic, paramedian section) (Ghetie, 1954).

In the horse the nuchal ligament consists of a **funicular** (funiculus nuchae) and a **laminar part** (lamina nuchae), both of which are paired. The funiculus nuchae arises from the external occipital protuberance, receives the lamina nuchae at the level of the third cervical vertebra and inserts to the spinous process of the fourth thoracic vertebra. It broadens in the wither region and continues caudally as the supraspinous ligament to the sacrum. The **lamina nuchae** originates from the spinous process of the axis, the dorsal tubercle of the successive cervical vertebrae and the spinous process of the last cervical vertebra. It radiates caudally into the nuchal funiculus to finally end on the spinous process of the first thoracic vertebra.

A bursa is interposed between the nuchal ligament and the second or third thoracic vertebra, the **supraspinous bursa** (bursa subligamentosa supraspinalis). It can be located in the live animal on a vertical line above the tuber of the spine of the scapula. Additional bursae may be found in some horses between the nuchal ligament and the atlas (bursa subligamentosa nuchalis cranialis) or the axis (bursa subligamentosa nuchalis caudalis) (Fig. 1-118).

Articulations of the ribs with the vertebral column (articulationes costovertebrales)

Most ribs have two articulations with the corresponding vertebrae, both of which act as hinge joints. These joints assist in expanding and narrowing of the thorax. The closer these joints are together the greater the mobility, with the highest mobility achieved in the caudal ribs.

The **costovertebral joint** (articulatio capitis costae) is a spheroidal joint, where the two articular surfaces of the head of the rib articulate with the socket formed by two articular facets of two adjacent thoracic vertebrae (the socket for the first rib is formed by the last cervical and the first thoracic vertebra), (Fig. 1-120). The intervertebral disc articulates with the interarticular groove of the costal head. Each articulation has its own joint capsule, which is reinforced by **ligamentous fibers** (ligamentum capitis costae radiatum), forming two separate joint cavities (Fig. 1-120). The **intercapital ligament** (ligamentum intercapitale) runs from the head of one rib, over the dorsal part of the disc, but under the dorsal longitudinal ligament to the head of the opposite rib. It is considered to play an important role in the pathogenesis of disc prolapses. The ligament connecting the most caudal ribs is smaller than the others and it is not as well developed in chondrodystrophic breeds. This is thought to account for the higher incidence of disc problems in those breeds. The ligament is joined to the intervertebral disc by a synovial membrane. A bursa is interposed between the intercapital ligament and the overlying dorsal longitudinal ligament.

The **costotransverse joint** (articulatio costotransversaria) is a sliding joint formed by the articular surfaces of the costal tubercle and the transverse process of the corresponding vertebra.

Joints of the thoracic wall (articulationes thoracis)

The **costochondral joints** (articulationes costochondrales) are the articulations between the ribs and the costal cartilages. These are symphyses in carnivores and the horse, but firm joints in pigs and ruminants. While the cranial costal cartilages are joined directly to the sternum, forming the **sternocostal joints** (articulationes sternocostales), the costal cartilages of the asternal ribs are joined together by elastic soft tissue forming the **costal arch** (arcus costalis).

The **sternocostal joints** (articulationes sternocostales) are condylar joints, functioning as hinge joints. They are formed by the condylar sternal extremity of the sternal costal cartilage and the matching articular cavities of the sternum. In the pig and the horse, the first rib of both sides have a common articular cavity on the manubrium of the sternum, whereas the articular surfaces (incisurae costales) of the other sternal ribs are placed laterally at the junction of the sternebrae, enclosed in tight joint capsules.

In juvenile subjects the individual sternebrae are joined together by the **intersternebral cartilages** (synchondroses sternales), which ossify later in life. The sternal cartilagenous joints comprise the intersternal synchondroses, the manubriosternal synchondrosis and the xiphosternal synchondrosis (Fig. 1-

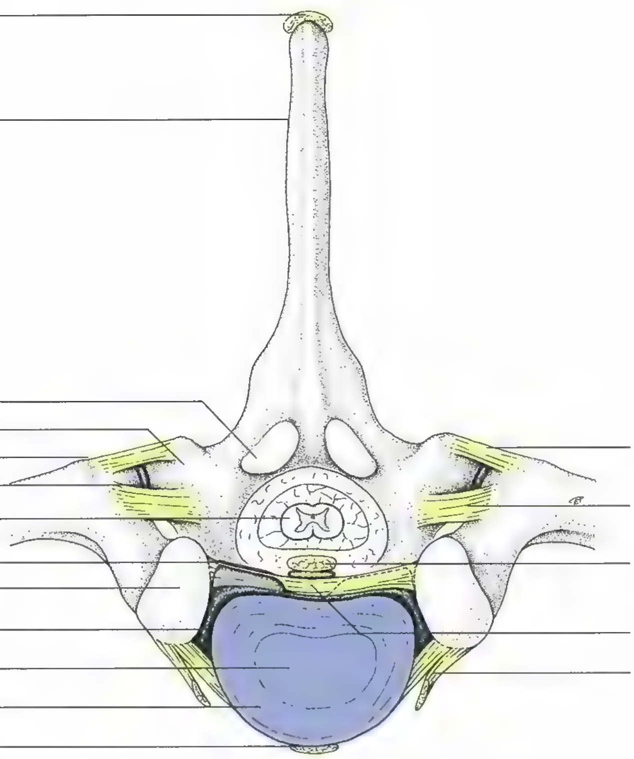

Fig. 1-120. Ligaments of the costovertebral joints of the horse (schematic, cranial aspect) (courtesy of Prof. Dr. Sabine Breit and Prof. Dr. W. Künzel, Vienna).

109 to 111). In ruminants and the pig, the manubrium is joined to the body of the sternum by a synovial joint (articulatio synovialis manubriosternalis). The **sternal ligament** (ligamentum sterni) lies on the dorsal surface of the sternum. It arises caudal to the first pair of ribs and broadens caudally to insert to the xiphoid cartilage in ruminants and the pig. In the horse, it divides into three branches which insert to the last sternal ribs and to the xiphoid cartilage. It is absent in some carnivores.

The vertebral column as a whole

The mobility of the vertebral column varies with the region. It is most free in the cervical spine, where the articular surfaces are large and orientated horizontally and the joint capsules are loose, which allows a larger degree of lateral, ventral, dorsal and rotational movements. In the thoracic and lumbar regions of the spine, mobility decreases from cranial to caudal. While in the cranial thoracic region rotation is possible, in the caudal region movement is more or less restricted to dorsal and ventral flexion (kyphosis and lordosis). A limited degree of lateral movement is still possible due to the intertransverse articulations of the lumbar vertebrae in the horse.

The **lumbosacral joint** (articulatio lumbosacralis) is formed by the last lumbar vertebra and the sacrum complemented by the intervertebral disc and supported by the iliolumbar ligament.

The processes of the individual sacral vertebrae are much reduced and their bodies and the intervertebral discs are firmly fused to form a single bone, the sacrum, which transmits the thrust of the hindlimbs to the rump more efficiently.

The caudal spine is mobile and the single vertebrae are joined together by intervertebral discs.

2 Fasciae and muscles of the head and trunk

H.-G. Liebich, J. Maierl and H. E. König

Fasciae

The head and trunk are enclosed by extensive sheets of connective tissue. These sheets of fasciae are interposed between the deeper structures and the skin or they cover and pass between the muscles. They form attachments for muscles and also facilitate movement of muscles across each other. Many of the deeper structures are also surrounded by fasciae, like the oesophagus, the trachea or the salivary glands. They also encase cutaneous muscles (mm. cutanei) and provide routes for the passage of blood vessels, lymphatics and nerves.

In general, the fascial system comprises a superficial and a deep layer. They are further subdivided according to their location:

- **Superficial fasciae of the head, neck and trunk:**
  - Superficial fascia of the head (fascia capitis superficialis),
  - Superficial fascia of the neck (fascia cervicalis superficialis),
  - Superficial fascia of the trunk (fascia trunci superficialis),
- **Deep fasciae of the head, neck, trunk and tail:**
  - Deep fascia of the head (fascia capitis profunda),
  - Deep fascia of the neck (fascia cervicalis profunda),
  - Deep fascia of the trunk (fascia trunci profunda),
  - Thoracolumbar fascia (fascia thoracolumbalis),
  - Spinocostotransversal fascia (fascia spinocostotransversalis) and
- **Deep fascia of the tail** (fascia caudae profunda).

Superficial fasciae of the head, neck and trunk

The **superficial fascia of the head** forms a mask-like covering over the whole head and continues on the neck like a cylinder. It lies directly beneath the skin and can be manually displaced in carnivores, whereas in ruminants and the horse it is adherent to the facial bones, where it is fused with the skin in the region of the nasal and frontal bones. It covers the parotid salivary gland, the masseter muscle (m. masseter) and the temporal muscle (m. temporalis). It encloses the cutaneous muscles of the head and parts of the auricular muscles. Rostrally it blends with the muscles of the cheek and nose, ventrally it covers the mandibular and laryngeal region.

The **superficial fascia of the neck** forms two layers. The superficial layer covers the superficial muscles of the neck (cervical part of the cutaneous muscle, brachiocephalic muscle, trapezius muscle), the deep layer covers the thoracic portions of the ventral serrated muscle and the splenius muscle and also encloses the common carotid artery (a. carotis communis). The fascia inserts in the nuchal ligament dorsally and continues caudally as the fasciae of the shoulder and trunk.

The **superficial fascia of the trunk** is very extensive and includes the cutaneous muscle of the trunk (m. cutaneous trunci). In the thoracic and lumbar regions it radiates into the thoracolumbar fascia. In ruminants and the horse it attaches to the dorsal spinous processes of the vertebrae. In carnivores it unites dorsally with the fascia of the opposite side, where in well-nourished animals large subfascial fat deposits can be found. Ventrally it blends with the musculature of the thorax and the linea alba and continues distally as the fascia of the thoracic and pelvic limbs.

Deep fasciae of the head, neck and trunk

The **deep fascia of the head** extends over the major part of the mandible, partly fused to the superficial fascia, as the **buccopharyngeal fascia** (fascia buccopharyngealis). A deep layer attached to the buccal wall and a more superficial layer passes under the masseter muscle and over the facial musculature to insert on the facial crest. Some muscles are ensheathed individually by the deep fascia of the head, such as the buccinator muscle (m. buccinator) and the canine muscle (m. caninus). Caudally it becomes the **temporal fascia** (fascia temporalis), which covers the temporal muscle and attaches to the orbita and the zygomatic arch and the **pharyngobasilar fascia** (fascia pharyngobasilaris), which extends between the pterygoid, the dorsal border of the mandible and the hyoid apparatus. In the region of the dorsum of the nose the deep and superficial fascia of the head are united and in carnivores the deep fascia fuses with the periosteum of the external surface of the parietal bone. The deep fascia of the head always lies beneath the large superficial blood vessels.

The **deep fascia of the neck** is two-layered. The superficial layer attaches to the wing of the atlas, the long muscles of the head (m. longus capitis) and scalene muscle (m. scalenus). Passing ventrally it encloses the oesophagus, the recurrent laryngeal nerve, the vagosympathetic trunk and the common carotid artery. It attaches to the hyoid apparatus and the pharyngobasilaris fascia cranially, the first ribs and the sternum caudally. The deep layer originates from the intertransversal muscles and encloses the long muscles of the neck. In the horse it detaches a septum between the guttural pouches.

The **deep fascia of the trunk** is relatively strong and in most parts enforced by tendinous tissue. Many muscles of the trunk arise from this fascia by means of an aponeurosis. The portion covering the thoracic and lumbar region is termed the **thoracolumbar fascia** and attaches to the spinous processes of the thoracic, lumbar and sacral vertebrae, the supraspinous ligament, the sacral tuberosity, the iliac crest and the coxal tuberosity. A strong part of this fascia forms the aponeurosis of the broadest muscle of the back (m. latissimus dorsi) and the caudal portion of the dorsal serrated muscle (m. serratus dorsalis caudalis). Cranioventrally, it continues as the **axillar fascia** (fascia axillaris) and caudally as the **gluteal fascia** (fascia glutaea). Ventrally, it forms the **abdominal tunic** (tunica flava abdominis), which mainly consists of elastic fibers in the large herbivores. In the inguinal region, several fibers branch to form the suspensory ligament of the penis (ligamentum suspensorium penis) and the mammary glands (apparatus suspensorius mammarius).

The deep fascia of the trunk becomes the **spinocostotransversal fascia** (fascia spinocostotransversalis) as it passes over the scapular region. This fascia forms three layers in the horse. It originates from the spinous processes of the first five thoracic vertebrae (spinal portion), the first eight ribs and the transverse processes of the corresponding vertebrae (costotransversal portion). The superficial layer of this fascia suspends the rump between the thoracic limbs and attaches to the serratus ventralis muscle. The middle layer encloses and separates the lateral muscles of the back (longissimus muscle, iliocostal muscle), the deep layer the medial muscles (semispinal muscle), to which it also gives attachment.

The deep fascia of the trunk also forms the internal fascia of the trunk. This fascia lies on the deep surfaces of the muscles of the body wall and blends with the serosal linings of the body cavities. It is termed the **endothoracic fascia** (fascia endothoracica) in the thoracic cavity, the **transversal fascia** (fascia transversalis) in the abdominal cavity and the **pelvic fascia** (fascia pelvis) in the pelvic cavity. The **iliac fascia** (fascia iliaca) covers the deep lumbar muscles.

The deep fascia of the tail originates from the gluteal fascia and fuses distally with the superficial fascia. It extends between the muscles of the tail and attaches to the caudal vertebrae.

Cutaneous muscles (musculi cutanei)

The cutaneous muscles are thin muscular layers, which are intimately adherent to the fasciae, with which they form an contractile extensive sheath covering most of the body. Its chief function is to tense and twitch the skin. In canivores it also enables mimic movements of the lips, nose and ears. These muscles can be divided into cutaneous muscles of the head, the neck and of the trunk.

Cutaneous muscles of the head (musculi cutanei capitis)

The cutaneous muscles of the head are contained within the superficial fascia of the head. They are part of the superficial facial musculature and are innervated by the facial nerve. They include the:

- Superficial sphincter muscle of the neck (m. sphincter colli superficialis),
- Cutaneous muscle of the face (m. cutaneous faciei),
- Deep sphincter muscle of the neck (m. sphincter colli profundus) and
- Frontal muscle (m. frontalis).

The **superficial sphincter muscle of the neck** is a thin transverse muscular band, which, in carnivores, extends along the ventral aspect of the laryngeal region, at the junction of the head and neck. It tenses the fascia of this region. The **cutaneous muscle of the face** is an extensive muscular sheet, covering the masseter muscle. It tenses and moves the skin of the head and draws the comissure of the lips caudally. The **deep sphincter muscle of the neck** lies beneath the platysma and cutaneous muscles of the face on the lateral aspect of head and neck. It tenses the superficial fascia in the laryngeal region. The **frontal muscle** (m. frontalis) is present in carnivores, ruminants and pigs, and is responsible for moving the skin on the forehead.

Cutaneous muscles of the neck (musculi cutanei colli)

The cutaneous muscles of the neck are innervated by the cervical branch (ramus colli) of the facial nerve. They are named according to their location and function:

- Superficial sphincter muscle of the neck (m. sphincter colli superficialis),
- Platysma muscle,
- Deep sphincter muscle of the neck (m. sphincter colli profundus) and
- Cutaneous muscle of the neck (m. cutaneus colli).

The **cervical superficial sphincter muscle** is only present in carnivores and is a direct continuation of the sphincter colli superficialis of the head and, as such, covers the ventral side of the neck from the head to the chest. The **platysma** is a well-developed muscular sheet in carnivores and pigs, which radiates into the facial cutaneous muscle. It tenses and moves the skin on the dorsal and lateral side of the neck. The **cervical cutaneus muscle** is situated at the ventral aspect of the neck. It originates from the manubrium of the sternum and covers the jugular groove. It is not present in carnivores.

Cutaneous muscles of the trunk (musculi cutanei trunci)

The cutaneous muscles of the trunk comprise the:

- Abdominal part of the cutaneous muscle (m. cutaneus trunci),
- Cutaneous omobrachial muscle (m. cutaneus omobrachialis),
- Peputial muscles (mm. preputiales) and
- Supramammary muscles (mm. supramammarii).

The **abdominal part of the cutaneous muscle** is an extensive muscle layer, which covers the lateral, ventral and dorsal walls of the thorax and abdomen. In carnivores the muscles of each side meet dorsally. It covers the latissimus dorsi craniodorsally, with which it forms the muscular axillary arch. The fibers converge ventrally towards the manubrium of the sternum and unite with the fibers of the opposite side. This muscle forms fibrous branches which cover the prepuce in male dogs as the preputial muscles and in female dogs to the mammary glands as the supramammary muscles. In large animals the cutaneous muscle of the abdomen is confined to the ventral aspect of the trunk and does not extend beyond the dorsal border of the fold of the flank, which it forms.

The abdominal part of the cutaneous muscle tenses and twitches the skin. It is assisted by the superficial fascia of the trunk.

The **cutaneous omobrachial muscle** is the extension of the abdominal part of the cutaneous muscle on the forelimb. It covers the lateral aspect of the shoulder and arm in ruminants and the horse and tenses the skin in that region.

The **preputial muscles** are present in carnivores, pigs and ruminants and are strongest in the bull. They can be divided into a cranial portion, which protracts the prepuce and a caudal portion which retracts the prepuce.

The **supramammary muscles** are a paired muscle in female carnivores, extending between the xiphoid to the pubic region, covering the mammary glands. They tense and move the skin of this region.

Muscles of the head (musculi capitis)

The muscles of the head can be grouped based on their embryologic origin, their innervation or their function. The system used in this book is based on the embryologic origin of the muscles from the different branchial arches and their innervation by the corresponding branchial nerves. The facial and masticatory musculature develop from the first and second branchial arches, the lateral and ventral walls of the laryngeal and pharyngeal region and their organs from the third and fourth branchial arch. The accompanying branchial nerves, the fifth, seventh, ninth and tenth cranial nerves innervate those muscles.

In the following description, the facial, masticatory and the pharyngeal musculature are described as groups, whereas muscles of specific organs, such as the larynx and eye are considered together with their related organs.

Facial musculature

The facial musculature can be subdivided into **superficial** and **deep layers,** which are both supplied by the facial nerve (Fig. 2-1 and 2, Table 2-1). The superficial layer includes the cutaneous muscles of the head and neck and a multitude of smaller muscles, which are responsible for the posture of the lips, nostrils, cheeks, the external ears and eyelids. Since they are responsible for the facial expression they are also termed mimic musculature. The **deep facial muscles** include the muscles attached to the hyoid bone, those considered to be part of the digastric muscle or extend into the middle ear (stapedial muscle). They are innervated by deep branches of the facial nerve.

The facial musculature can be divided into:

- **Muscles of the lips and cheeks:**
  - Orbicular muscle of the mouth (m. orbicularis oris),
  - Incisive muscle (mm. incisivi),
  - Nasolabial levator muscle (m. levator nasolabialis),
  - Levator muscle of the upper lip (m. levator labii superioris),
  - Canine muscle (m. caninus),
  - Depressor muscle of the upper lip (m. depressor labii superioris),
  - Depressor muscle of the lower lip (m. depressor labii inferioris),
  - Levator muscle of the chin (m. mentalis),
  - Zygomatic muscle (m. zygomaticus) and
  - Buccinator muscle (m. buccinator).
- **Muscles of the nose:**
  - Apical dilator muscle of the nostril (m. dilatator naris apicalis),
  - Medial dilator muscle of the nostril (m. dilatator naris medialis,
  - Lateral muscle of the nose (m. lateralis nasi) and
  - Transverse muscle of the nose (m. transversus nasi).
- **Extraorbital muscles of the eyelids:**
  - Orbicular muscle of the eye (m. orbicularis oculi),
  - Levator muscle of the medial angle of the eye (m. levator anguli oculi medialis),
  - Levator muscle of the lateral angle of the eye (m. levator anguli oculi lateralis) and
  - Malar muscle (m. malaris).
- **Muscles of the external ear:**
  - Scutular muscle (m. scutularis),
  - Parotido-auricular muscle (m. parotidoauricularis),
  - Caudal auricular muscles (mm. auriculares caudales),
  - Dorsal auricular muscles (mm. auriculares dorsales),
  - Rostral auricular muscles (mm. auriculares rostrales),
  - Deep auriculares muscles (mm. auriculares profundi),
  - Styloauricular muscle (m. styloauricularis).

Muscles of the lips and cheeks (musculi labiorum et buccarum)

The **orbicular muscle of the mouth** is the sphincter muscle of the mouth. It surrounds the opening of the mouth and

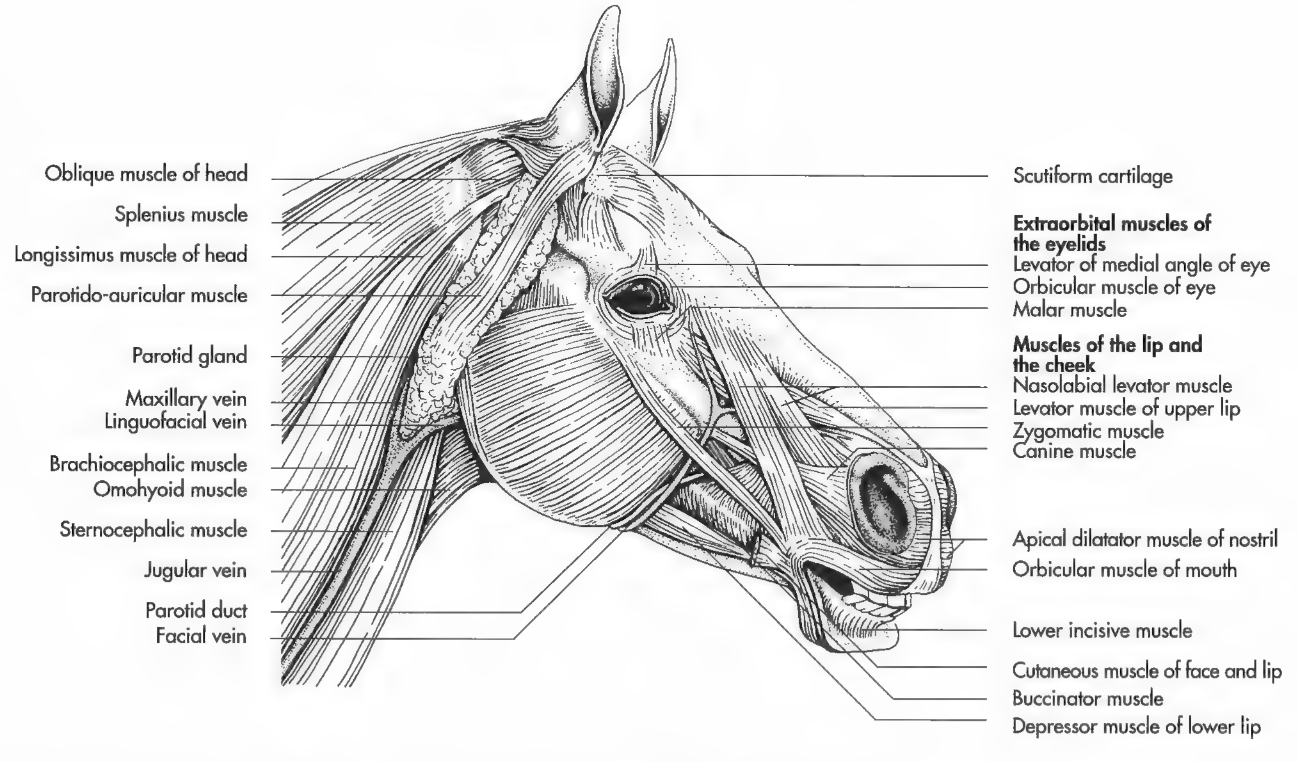

Fig. 2-1. Superficial muscles of the head of the horse (schematic, lateral aspect) (Ghetie, 1954).

forms the principal component of the lips (Fig. 2-1). It is made up of multiple muscle bundles, which are intimately connected to the skin and the mucosa/submucosa. Fibers of the other muscles of the lips and cheeks radiate into the orbicularis oris.

In the dog this muscle is stronger in the upper lip, than in the lower, where it is interrupted in the median segment. The orbicularis oris shows a similar interruption in the upper lip of ruminants, which accounts for the limited degree of motion possible to this segment. The roots of the tactile hairs are embedded within the muscular tissue of the orbicularis oris.

The **incisive muscles** lie directly beneath the submucosa of the lips. They arise as small muscle plates from the alveolar borders of the incisive bone and the mandible and radiate into the orbicularis oris (Fig. 2-1). They raise the upper lip and pull the lower lip downward.

The **nasolabial levator muscle** originates from the fascia of the nasal and frontal region (Fig. 2-1). It spreads out to form a flat, band-shaped muscle in all domestic animals. In ruminants and the horse it divides into two branches, through which the caninus muscle passes. It inserts in the superior portion of the orbicularis oris and in the lateral wall of the nares and elevates the upper lip and dilates the nostril.

The **levator muscle of the upper lip** is the strongest muscle of the facial group. It originates from the medial angle of the eye, although its exact origin varies in the different domestic species (Fig. 2-1). It inserts, with several small tendons of insertion, on the lateral wall of the nostrils and the upper lip (carnivores, pigs, ruminants). In the horse it forms a broad common tendon with the corresponding muscle of the opposite side with which it inserts in the median segment of the upper lip.

In carnivores it originates from the facial surface of the maxilla, caudoventral to the infraorbital foramen and radiates with delicate tendons into the lateral wall of the nostrils and the upper lip. In the pig it fills the canine fossa (fossa canina) and inserts on the rostral part of the rostral bone.

The levator muscle of the upper lip of ruminants forms several thin tendons of insertion, with which it inserts on the dorsolateral wall of the nostril and the upper lip. In the horse the long flat belly of this muscle covers the maxilla and parts of the lacrimal and zygomatic bones.

The **canine muscle** lies deep to the levator muscle of the upper lip in most domestic species. In carnivores it radiates into the upper lip at the level of the canine teeth. In ruminants it originates ventral to the levator muscle of the upper lip from the facial tuberosity, passes under the nasolabial levator muscle and inserts on the lateral wall of the nostril and the adjacent parts of the upper lip.

In the horse the canine muscle is a thin muscular plate, which extends between the rostral end of the facial crest and the lateral wall of the nostril (Fig. 2-1).

The **depressor muscle of the upper lip** is only present in ruminants and pigs. It originates rostral to the facial tuberosity and ventral to the canine muscle. In the pig, it forms a long tendon, which unites with the tendon of insertion of the corresponding muscle of the opposite side and inserts on the ros-

Tab. 2-1. Muscles of the lips and cheeks.

Name Innervation	Origin	Insertion	Action
Orbicular muscle of the mouth Facial nerve, buccolabial branch	Circular muscle		Closes the opening of the mouth
Incisive muscles Facial nerve, buccolabial branch – Upper incisive muscle – Lower incisive muscle	 Alveolar arch Alveolar arch	 Orbicular muscle of the mouth Orbicular muscle of the mouth	 Raises the upper lip Pulls lower lip down
Nasolabial levator muscle Facial nerve, zygomatic branch	Forehead-, lateral surface of the nasal and maxillary bones	Orbicular muscle of the mouth near the nasal aperture	Raises the upper lip Widens external naris
Levator muscle of the upper lip Facial nerve, buccolabial branch	Variably on the maxillary bones	Upper lip	Raises and draws back upper lip and nasal plane
Canine muscle Facial nerve, buccolabial branch	Rostrally on the facial crest and on the facial tuberosity	Near the nasal aperture	Widens external naris and draws back upper lip
Depressor muscle of the upper lip (excl. horse) Facial nerve, buccolabial branch	Facial tuberosity	Upper lip	Pulls upper lip down
Depressor muscle of the lower lip Facial nerve, buccolabial branch	Maxillary tuberosity	Lower lip	Pulls lower lip down
Levator muscle of the chin Facial nerve, buccolabial branch	On the lateral surface of the alveolar border of the mandible	Radiates into lower lip	Movement of the chin
Zygomatic muscle Facial nerve, zygomatic branch	Zygomatic bone	Orbicular muscle of the mouth	Draws back the angle of the mouth
Buccinator muscle Facial nerve, buccolabial branch	Maxilla and mandible	Middle tendon	Narrows cheek pouch

tral part of the rostral bone. In ruminants it splits into several thin branches, which form a network of fibers in the upper lip and muzzle.

The **depressor muscle of the lower lip** is present in all domestic mammals, except carnivores. In ruminants it is a small and thin detachment of the molar part of the buccinator muscle, which radiates into the lower lip on the lateral aspect of the mandible. In the horse this muscle originates from the maxillar tuberosity and the buccinator muscle, extends rostrally under the extensive cutaneous muscle of the face and lips, on the lateral surface of the molar part of the mandible and radiates into the lower lip.

The **levator muscle of the chin** is a weak muscle, infiltrated by fat and connective tissue, which appears to be a detachment of the buccinator. It forms the principal component of the chin, which is well-developed in the horse, but less distinct in other domestic species.

The **zygomatic muscle** is a thin muscle plate, which originates rostral to the facial crest in the horse and from the fascia covering the masseter muscle in ruminants (Fig. 2-1). It inserts with the orbicular muscle of the mouth at the commissure of the lips. In carnivores it originates from the scutiform cartilage as a strap-like muscle, which fans out to end on the corner of the mouth rostrally and the fascia of the neck ventrally.

The **buccinator muscle** forms the muscular wall of the oral cavity. It extends between the alveolar processes of the maxilla and mandible as a flat muscular plate (Fig. 2-1). It can compress the vestibule of the mouth, thus returning food to the masticatory surface of the teeth. In ruminants and the horse it can be divided into a buccal part (pars buccalis) rostrally and a deep molar part (pars molaris) caudally. In carnivores it is divided into maxillary and mandibular parts (Fig. 2-1).

In carnivores both portions originate from the alveoli of the last maxillary and mandibular molars as a thin muscular plate. The stronger maxillary portion passes along the rostral border of the masseter muscle, curves beneath the superficial part of the mandibular portion rostrodorsally and inserts rostral to the infraorbital foramen on the maxilla. The fibers of the weaker mandibular portion are directed in the opposite direction. They extend from the lower lip and the alveolar border of the first three premolars caudodorsally, where they insert on the maxilla.

In ruminants and the horse the buccal and molar portions are easily dissected from each other. The buccal portion forms the superficial part of the cheek. It is incompletely pennate with a longitudinal raphe on which most of the muscle fibers converge. It has a stronger dorsal and a weaker ventral part. The molar portion originates from the alveolar border of the caudal

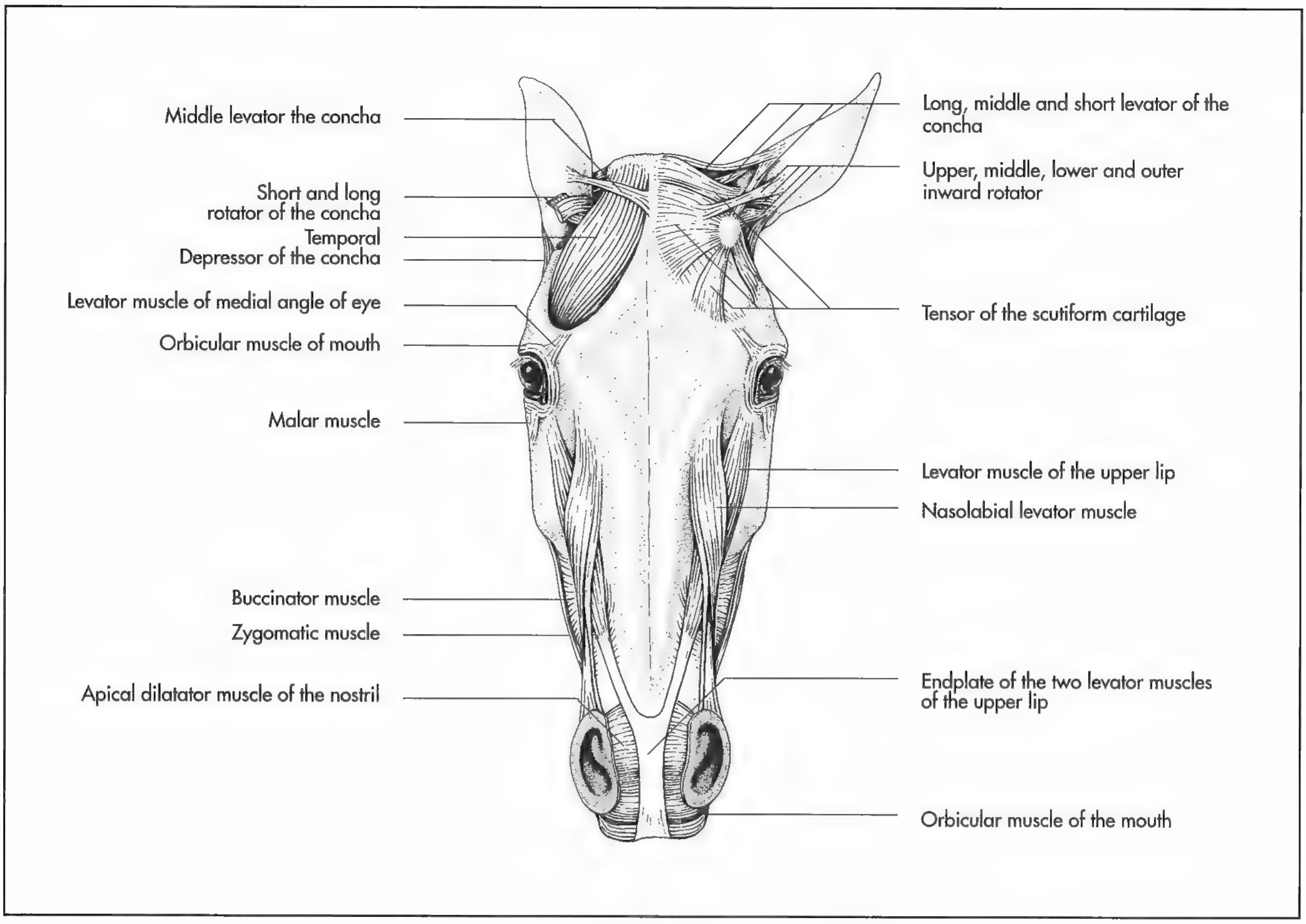

Fig. 2-2. Superficial muscles of the head of the horse (schematic, frontal aspect) (Ghetie, 1971).

cheek teeth and from the coronoid process of the mandible and blends with the orbicular muscle of the mouth rostrally. It is closely attached to the mucous membranes of the mouth and the buccal glands.

Muscles of the nose

Muscles of the nose are rudimentary in carnivores and in the pig, but better developed in ruminants and the horse. Their main function is the dilatation of the nostrils (Fig. 2-1 and 2-2).

In the horse this group comprises:

- Apical dilatator muscle of the nostril (m. dilatator naris apicalis),
- Lateral muscle of the nose (m. lateralis nasi) and
- Medial dilatator muscle of the nostril (m. dilatator naris medialis).

Extraorbital muscles of the eyelids (musculi extraorbitales)

The **orbicular muscle of the eye** is the sphincter muscle of the palpebral fissure (Fig. 2-1 and 2, Table 2-2). The stronger deep portion (pars orbitalis) lies directly on the orbital wall, whereas the smaller superficial portion (pars palpebralis) radiates into the lids. It closes the palpebral fissure.

The **levator muscle of the medial angle of the eye** is a thin, small muscular plate in all domestic mammals, except in carnivores, in which it is a strong muscular band. It originates from the frontal fascia and extends into the upper lid dorsomedially (Fig. 2-2). It lifts the medial portion of the upper lid.

The **levator muscle of the lateral angle of the eye** is present in carnivores only. It extends from the temporal fascia to the lateral palpebral angle, which it draws caudally.

The **malar muscle** is a weak muscle in domestic mammals, except ruminants. It is thought to be the palpebral detachment of the deep sphincter muscle of the neck (Fig. 2-2). In the dog it consists of a few isolated muscle bundles, partly covered by the platysma muscle, which extend from the mandible dorsoventrally to the orbicular muscle of the mouth and the maxilla. In ruminants its fibers are orientated at a right angle to the fibers of the zygomatic muscle and fan out to attach to the lacrimal bone at the medial canthus of the eye. It is a very weak muscle in the horse, and originates from the deep facial fascia in the region of the facial crest and combines with the palpebral portion of the orbicular muscle of the eye.

Tab. 2-2. Extraorbital muscles of the eyelids.

Name Innervation	Origin	Insertion	Action
Orbicular muscle of the eye Facial nerve, zygomatic branch	Circular muscle of the eye		Closes the palpebral fissure
Levator muscle of the medial angle of the eye Facial nerve, zygomatic branch	Nasofrontal fascia	Medial on the eye lid	Levator of the medial part of the eyelid
Retractor muscle of the lateral angle of the eye Facial nerve, zygomatic branch	Temporal fascia	Lateral palpebral angle	Retractor of the lateral palpebral angle
Malar muscle Facial nerve, buccolabial branch	Facial fascia	Lower eye lid	Draws lower eye lid downward

Muscles of the external ear (musculi auriculares)

There are numerous small muscles of the external ear in the domestic mammals, which either originate from the scutiform cartilage or directly from the skull. Their fibers converge towards the auricle from all directions (Fig. 2-3). They can be grouped by location and function into muscles which draw the ear downward, upward, outward, inward, tense the scutiform cartilage and rotate the ear. There are several small muscle bundles in additon to the muscles descibed below, which lie directly on the scutiform cartilage and narrow or widen the entrance to the conchal canal.

The **scutular muscle** is a thin muscular plate, which connects the scutiform cartilage to the skull and can change the position of it (Fig. 2-3). It can be subdivided into the frontoscutular, the interscutular, cervicoscutular muscles; their names indicating their location.

The **parotido-auricular muscle** is a long muscular band, which extends from the cranial cervical and the parotid region to the ventral angle of the scutiform cartilage. It draws the ear ventrally and caudally (Fig. 2-1 and 3).

The **caudal auricular muscles** consist of a long portion, the middle cervicoauricular muscle (m. cervicoauricularis medius) and a short portion, the deep cervicoauricular muscle (m. cervicoauricularis profundus). Both portions arise from the cranial part of the neck and end on the lateral aspect of the scutiform cartilage. They draw the external ear outward and backward.

The **dorsal auricular muscles** comprise three separate muscles, which insert on the dorsal aspect of the external ear. The superficial cervicoauricular muscle (m. cervicoauricularis superficialis) originates from the region of the cranial neck, the parietoauricular muscle (m. parietoauricularis) from the parietal part of the temporal bone and the accessory superficial cervicoauricular muscle (m. cervicoauricularis superficialis accessorius) from the scutiform cartilage. They elevate the external ear and draw it backward or forward.

The group of the **rostral auricular muscles** include four small muscles, which are termed according to their location (Fig. 2-3): dorsal superficial scutuloauricular, middle superficial scutuloauricular, ventral superficial scutuloauricular and zygomaticoauricular muscles. They share a common insertion on the rostromedial aspect of the external ear and raise the ear. The zygomaticoauricular muscle also rotates the base of the ear forward.

The **deep auricular muscles** extend between the ventral aspect of the scutiform cartilage and the base of the ear (Fig. 2-3). They include a long portion (m. scutuloauricularis profundus major) and a short portion (m. scutuloauricularis profundus minor) and rotate the external ear.

The **styloauricular muscle** is a narrow muscular band, which goes to the medial aspect of the scutiform cartilage and shortens the conchal canal (Fig. 2-3).

The muscles of the external ear are innervated by two branches of the facial nerve. These branches separate from the main nerve after it has passed through the stylomastoideum foramen and extend to the dorsal part of the ear rostral and caudal to the scutiform cartilage (n. auriculopalpebralis, n. auricularis caudalis).

Mandibular muscles

The mandibular muscles comprise the muscles of mastication and the superficial muscles of the mandibular space. They are innervated by the mandibular nerve, which is the third main branch of the first branchial nerve, the trigeminal nerve (cranial nerve V). This group is responsible for the movements of the jaw, which are necessary for mastication. It also covers the mandibular space and the hyoid apparatus ventrally.

The mandibular muscles include:

- **Muscles of mastication:**
  - Masseter muscle (m. masseter),
  - Medial and lateral pterygoid muscles (mm. pterygoidei medialis et lateralis),
  - Temporal muscle (m. temporalis),
- **Superficial muscles of the mandibular space:**
  - Digastric muscle (m. digastricus) and
  - Mylohyoid muscle (m. mylohyoideus).

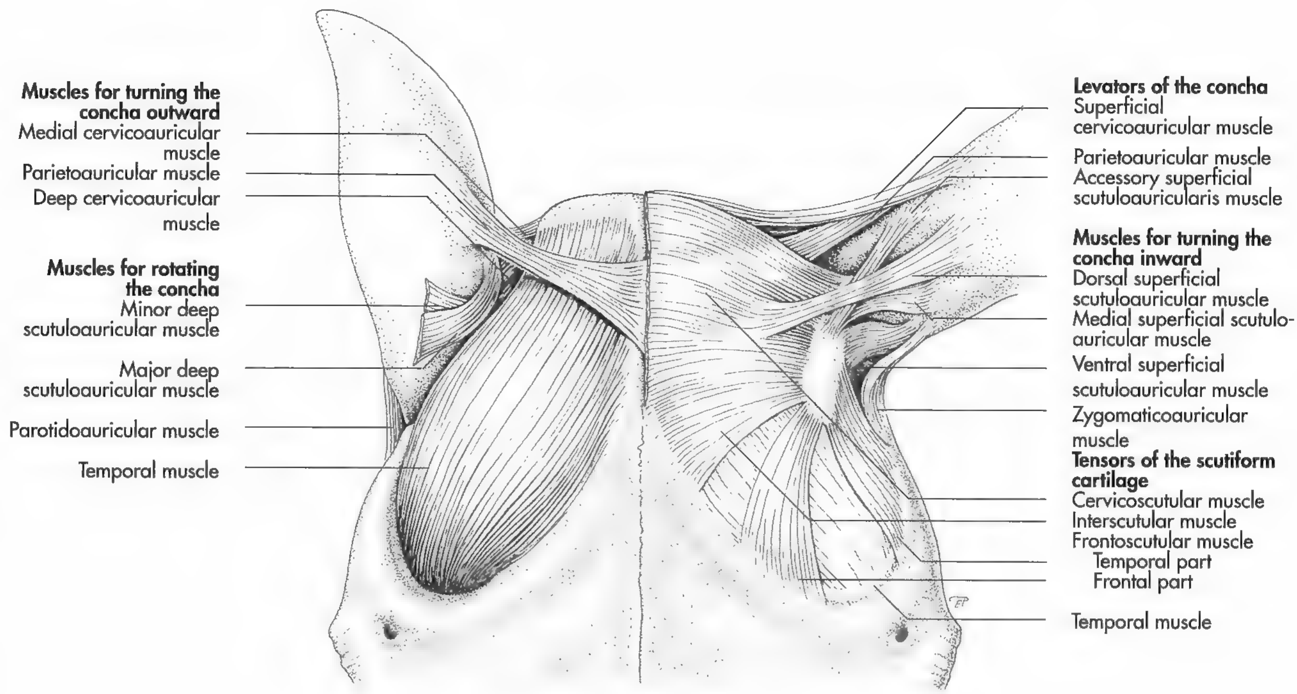

Fig. 2-3. Muscles of the external ear of the horse (schematic, frontal aspect) (Ghetie, 1971).

Muscles of mastication

The muscles that are responsible for mastication are in general strong and show marked species specific variations due to the different anatomy of the whole masticatory apparatus, including the skeletal components, the teeth and the temporomandibular joint (Fig. 2-4 to 2-7, Table 2-3).

The **masseter muscle** is a broad multipennate muscle with multiple tendinous intersections. It originates from the ventral border of the zygomatic arch and the facial crest and inserts on the lateral aspect of the mandible, extending from the facial notch to the temporomandibular joint.

The masseter muscle of carnivores is separated into three layers (superficial, middle, deep) by tendinous sheets (Fig. 2-4). The superficial portion is the strongest and originates from the rostral half of the zygomatic arch, passes over the ramus of the mandible caudoventrally and inserts, partly on the ventrolateral surface of the mandible. The rest of the muscle passes around the ventral border of the mandible and the angular process to inserts on the ventromedial side, where it covers the digastric muscle. The middle layer, the weakest part of the masseter muscle, originates from the ventral border of the zygomatic arch, medial to the superficial layer and inserts on the lateral surface of the mandible. It is not possible to isolate the rostral origin of the deep layer, since it is fused to the temporalis muscle, caudally it originates from the medial surface of the zygomatic arch.

In the pig the three layers are firmly fused and difficult to dissect. In the ox the tendinous intersections are pronounced, forming five distinct parts. The change of fibre direction between each portion increases the masticatory force of this muscle. The superficial portion extends from the facial tuberosity, to the caudal border of the mandible. The deep layer originates from the facial crest and the zygomatic arch, passes caudoventrally and inserts on the lateral surface of the mandibular ramus.

The masseter muscle of the horse shows up to fifteen tendinous intermuscular strands, which are orientated sagitally and divide the muscle into multiple layers. The superficial layers arise from the facial crest, pass caudoventrally and insert on the ventral and caudal borders of the mandible. The deeper layers originate from the zygomatic arch, pass over the ramus of the mandible in a horizontal direction and unite with the superficial portions, with which they insert on the lateral surface of the ramus of the mandible. If the masseter muscles of both sides act together, they force the upper and lower jaw together, if acting singly, they move the mandible to the side of the contracting muscle, which is essential for the grinding process of herbivores.

The **pterygoid muscles** pass from the palatine, pterygoid and sphenoid bones to the medial aspect of the mandible (Fig. 2-5). The lateral pterygoid muscle (m. pterygoideus lateralis) is the smaller of the two. It originates from the pterygoid process of the basisphenoid bone, passes caudoventrally and inserts on the medial surface of the ramus of the mandible near the condylar

Tab. 2-3 Muscles of mastication.

Name **Innervation**	**Origin**	**Insertion**	**Action**
Masseter muscle Masseteric nerve of the mandibular nerve	Facial crest and zygomatic arch	Lateral surface of the mandible and intermandubular region	Raises and draws mandible sidewards
Lateral pterygoid muscle Branch to lateral pterygoid from the mandibular nerve	Pterygoid process of the sphenoid bone	Medial surface of the mandible and the condylar process	Raises, pushes and draws forward the mandible
Medial pterygoid muscle Branch to medial pterygoid from the mandibular nerve	Pterygoid process of the sphenoid, pterygoid bone, and the perpendicular plate	Medial surface of the mandible	Raises mandible
Temporal muscle Deep temporal nerve from the mandibular nerve	Temporal fossa	Coronoid process of the mandible	Raises mandible in order to close the mouth

process. The much larger medial pterygoid muscle (m. pterygoideus medialis) occupies a position on the medial surface of the mandible similar to that of the masseter laterally. It extends from the basisphenoid and palatine bones to the ventral border of the mandible and the medial surface of the ramus of the mandible.

In carnivores both parts are fused at their origin. They originate together from the lateral surface of the pterygoid, sphenoid and palatine bones. Their fibres insert on the medial surface of the mandible, ventral to the mandibular foramen and on a fibrous raphe; that passes between the insertion of this muscle and the masseter.

In the horse the medial pterygoid muscle is covered by the lateral one. The mandibular nerve passes across the lateral surface of the medial pterygoid muscle, thus separating the two pterygoid muscles. The stronger medial pterygoid muscle originates from the vertical part of the pterygoid, sphenoid and palatine bones and fans out to forms an extensive insertion on the medial surface of the ramus of the mandible. The pterygoid muscles complement the masseter in its action. If contracting bilaterally they raise the mandible, if acting unilaterally they draw the mandible to the side of the contracting muscle. The lateral portion is also able to move the mandible rostrally, especially when the mouth is opened.

The **temporal muscle** occupies the temporal fossa, its size varying in the different species depending on the size of the fossa (Fig. 2-2). It originates from the temporal crest, which forms the edge of the temporal fossa, and from the temporal fascia. From there it extends downward, covered by the auricular muscles and inserts on the coronoid process of the mandible. It is the strongest muscle of the head in carnivores. The margins of its origin are the temporal line, the temporal crest, the nuchal crest, the zygomatic process of the temporal

Tab. 2-4. Superficial muscles of the mandibular space.

Name **Innervation**	**Origin**	**Insertion**	**Action**
Digastric muscle Rostral part: Nerve to mylohyoid from the mandibular nerve Caudal part: Digastric branch from the facial nerve	Paracondylar process	Medial on the body of the mandible	Draws mandible downwards; opens the mouth
Occipitomandibular portion Digastric branch from the facial nerve	Paracondylar process	Angle of the mandible	Opens the mouth
Mylohyoid muscle Branch to mylohyoid from the mandibular nerve	Mylohyoid line	Median raphe	Supports and lifts the tongue

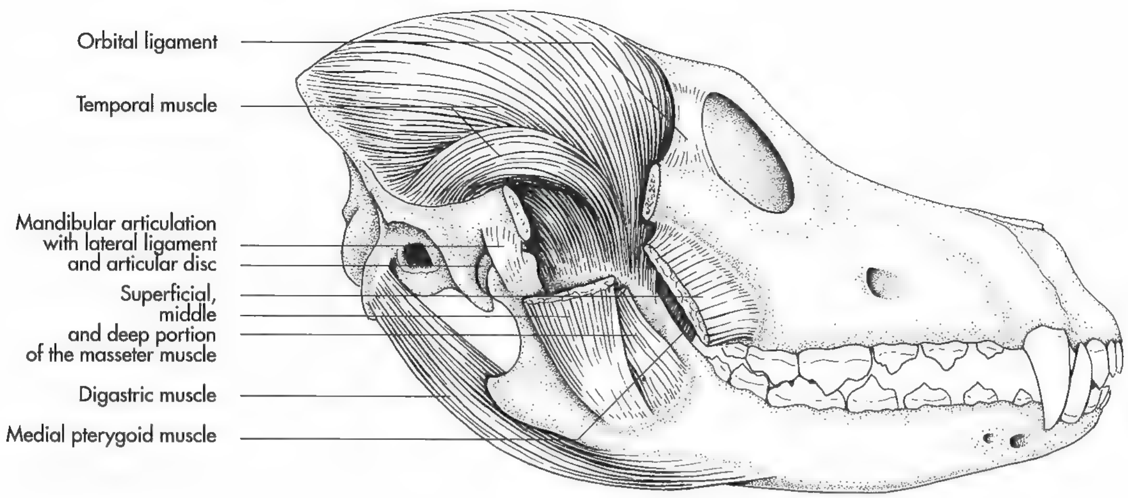

Fig. 2-4. Mandibular muscles of the dog (schematic, lateral aspect, zygomatic arch removed).

bone and the medial surface of the temporal fossa. From its extensive origin the large muscle bundles curve cranioventrally beneath the zygomatic arch and the orbital ligament and pass around the coronoid process of the mandible to which they insert. A tendinous branch fuses with the deep layer of the masseter muscle. In dolichocephalic dogs the temporal muscle meets the corresponding muscle of the opposite side in the midline and forms a mid-line sulcus. In brachycephalic dogs the two muscles do not meet and therefore no sulcus is visible, except for a small indentation between the interparietal bones in some breeds of dog.

While the temporal muscle is indistinct in ruminants it is visible under the skin in the horse. However, even in the horse the temporal muscle is not well developed compared to the other masticatory muscles. It originates from the borders of the temporal fossa, the temporal line, external sagittal crest, the nuchal crest and the pterygoid crest and the surface of the temporal fossa, which it occupies completely. It partly fuses with the masseter and inserts to the coronoid process of the mandible. It raises the mandible, acting together with the other masticatory muscles.

Superficial muscles of the mandibular space

The superficial muscles of the mandibular space assist the muscles of mastication. They cover the ventral side of the lingual muscles in the mandibular space (Fig. 2-4 to 2-7, Table 2-4).

Although named the **digastric muscles** it is a single-bellied muscle in domestic animals, except in the horse, where it has a caudal and a rostral belly. In the other domestic mammals its evolutionary bipartite structure is indicated by a fibrous intersection.

The rostral part is innervated by the mylohyoid nerve (n. mylohyoideus), which is a branch of the mandibular nerve (n. mandibularis), the caudal part by the digastric branch (ramus digastricus) of the facial nerve (n. facialis) (cranial nerve VII). It extends between the paracondylar process of the occiput and the medial surface of the mandible (Fig. 2-4).

In carnivores the digastric muscle is a strong single-bellied muscle, with delicate tendinous strands marking the division between the rostral and caudal portion. Unlike the rest of the domestic animals this muscle inserts on the medial surface of the ventral border of the mandible at the level of the canine tooth.

In ruminants the tendinous intersection between the two bellies is indistinct. It originates from the paracondylar process of the occiput and inserts on the medial surface of the mandible. A transverse muscular band extends between the two corresponding muscles of each side.

In the horse the caudal belly branches to form a lateral portion (pars occipitomandibularis) which inserts on the angle of the mandible (Fig. 2-5). The rest of the caudal belly passes ventrally and rostrally on the medial surface of the medial pterygoid muscle. It continues as an intermediate round tendon, which perforates the tendon of insertion of the stylohyoid muscle.

After passing beneath the basihyoid bone it forms the rostral belly, which attaches to the medial surface of the ventral border of the body of the mandible. It depresses the mandible and opens the mouth.

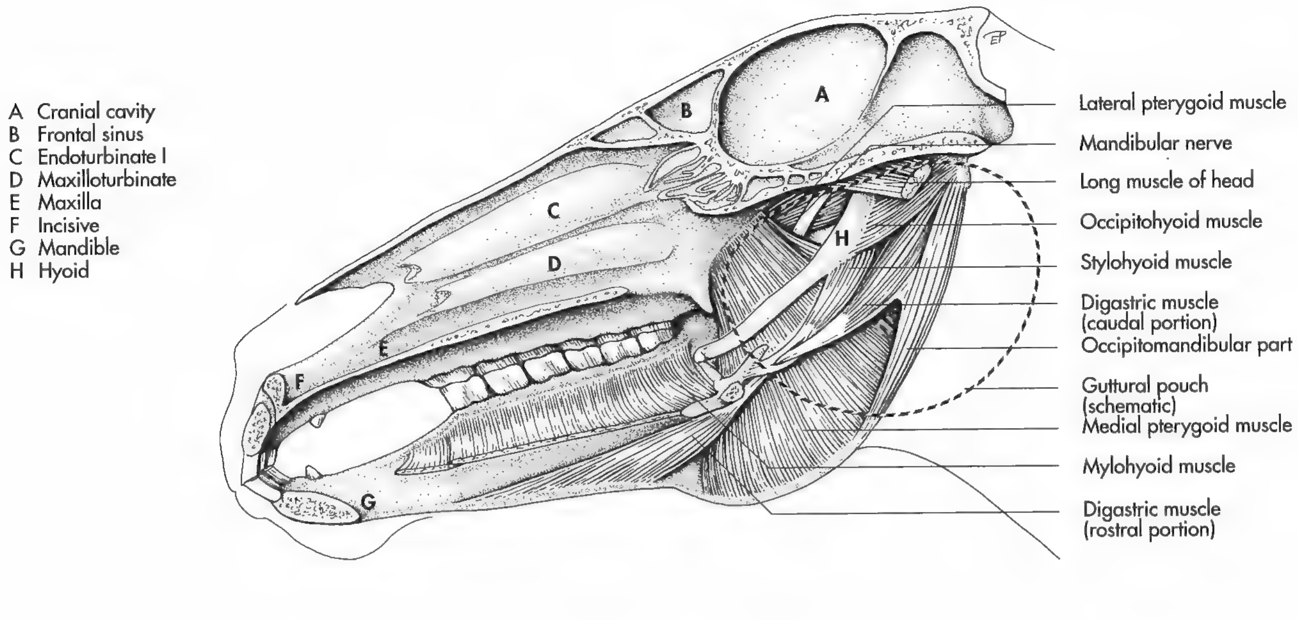

Fig. 2-5. Mandibular muscles of the horse (schematic, medial aspect) (Ellenberger and Baum, 1943).

The **mylohyoid muscle** forms a sling between the inner surface of the body of the mandible. Based on its innervation by the mylohyoid nerve, a branch of the mandibular nerve it is assigned to the mandibular group. According to its function it can also be seen as a lingual muscle. Its fibres originate from the mylohyoid line on the medial surface of the mandibular body and unite with those of the opposite side in the midline of the mandibular space forming a median fibrous raphe. It supports the tongue and raises it towards the palate (Fig. 2-5 and 6).

Specific muscles of the head

The specific muscles of the head represent the functional continuation of the muscles of the neck onto the head, thus they belong strictly speaking to the muscles of the trunk (Fig. 2-7 and 9, Table 2-5). Since their main function is the coordination of the movements of the head, especially of the atlanto-occipital and atlanto-axial joints, they are described as a separate group. They are responsible for shaking, tilting, flexing and turning the head. This group is especially well developed in the pig, which enable it to dig the ground for food and in ruminants, which use their horns as weapons. Depending on their location they are innervated by the dorsal and ventral branches of the first and second cervical nerve, with the exception of the long muscle of the head, which is innervated by the first to sixth cervical nerve.

The **major dorsal straight muscle of the head** (m. rectus capitis dorsalis major) extends between the spine of the axis and the squamous part of the occiput. It can be divided into a deep and superficial portion in all domestic mammals. In carnivores and the pig the muscles of either side meet in the midline, whereas in ruminants and the horse they lie lateral to the nuchal ligament (Fig. 2-12). In carnivores it is covered by the semispinal muscle of the head from the atlas to the nuchal crest.

The **minor dorsal straight muscle of the head** (m. rectus capitis dorsalis minor) lies directly over the dorsal atlanto-occipital membrane, deep to the long muscle of the head and extends between the occiput and the atlas. In carnivores and the horse it attaches to the dorsal arch of the atlas caudally and to the occiput dorsally over the foramen magna.

Both dorsal straight muscles of the head act as extensors of the atlanto-occipital joint, thus raising the head.

The **lateral straight muscle of the head** (m. rectus capitis lateralis) is a small muscular band, which occupies the alar fossa of the atlas and extends from the ventral arch to the paracondylar process of the occiput (Fig. 2-7). It flexes the atlanto-occipital joint and tilts the head.

The **ventral straight muscle of the head** (m. rectus capitis ventralis) runs between the ventral arch of the atlas and the basioccipital bone, to which it inserts between the muscular tubercle and the tympanic bulla (Fig. 2-7). It flexes the atlanto-occipital joint.

The **cranial oblique muscle of the head** (m. obliquus capitis cranialis) is a short muscle, which extends obliquely craniolaterally over the atlanto-occipital joint, covered by the splenius and parts of the brachiocephalic muscle (Fig. 2-7 and 12). In carnivores it is divided into two portions. The main portion originates from the lateral and ventral portion of the wing of the atlas and inserts on the mastoid process of the

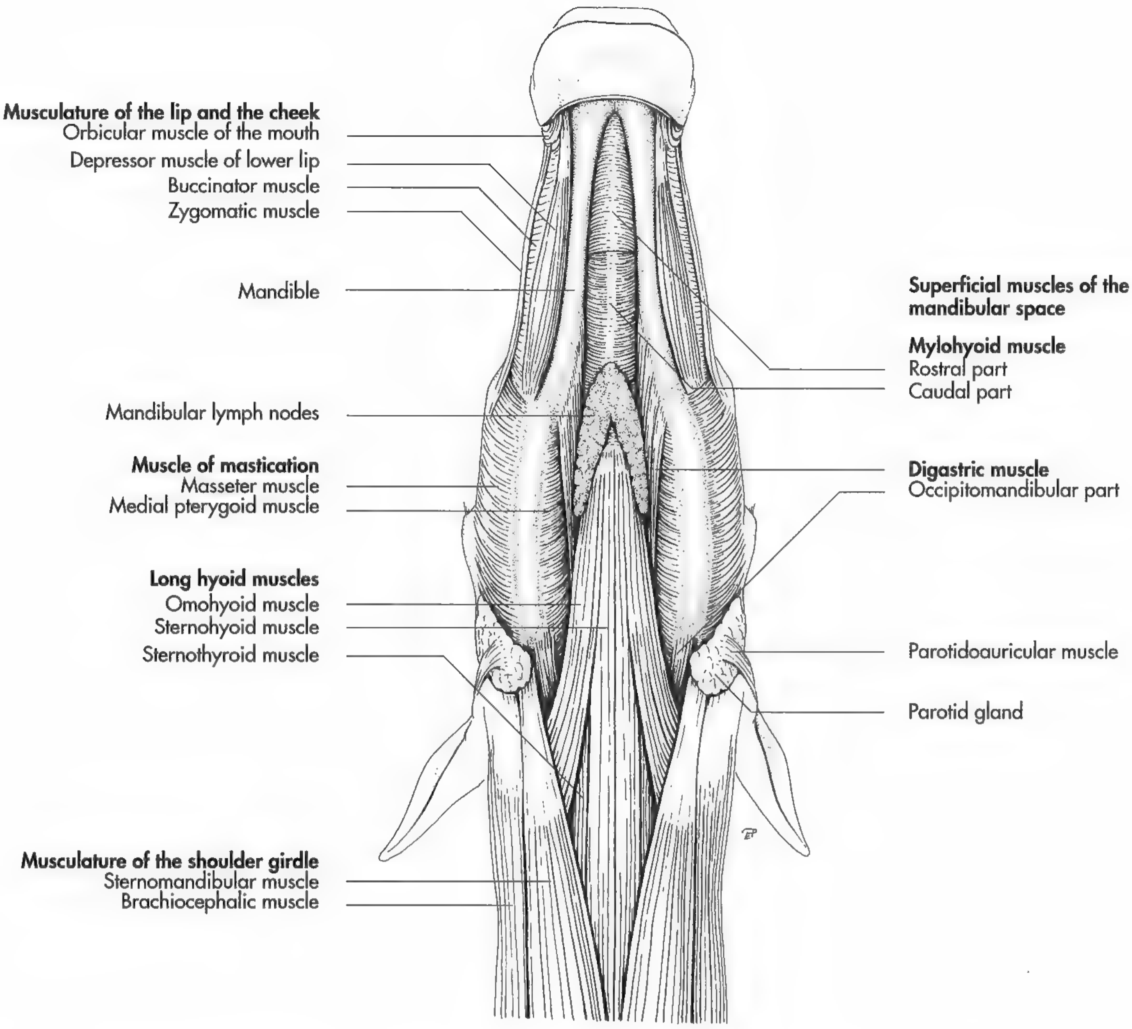

Fig. 2-6. Superficial muscles of the head and cranial neck region of the horse (schematic, ventral aspect) (Popesko, 1979).

temporal bone and to the nuchal crest. It extends the atlanto-occipital joint and bends the head to the contracting side, when contracting unilaterally.

The **caudal oblique muscle of the head** (m. obliquus capitis caudalis) covers the atlas and axis dorsally. It originates from the spinous process of the axis, passes obliquely craniolaterally to its insertion on the wing of the atlas (Fig. 2-9 and 12). If contracting unilaterally it rotates the atlas and thus the head on the dens of the axis. Contracting bilaterally, they act as fixators of the head.

The **long muscle of the head** (m. longus capitis) represents the cranial continuation of the long muscle of the neck. It flexes the atlantooccipital joint and draws the head sideways and the neck downward (Fig. 2-7). It is a strong muscle, which lies on the lateral and ventral sides of the second to sixth cervical vertebrae. It originates from the caudal branches of the transverse processes and inserts on the muscular tubercle of the basioccipital bone. In the horse it is slightly shorter than in carnivores, originating from the second to fourth cervical vertebra. Before its insertion it unites with the corresponding muscle of the opposite side in the midline, between the guttural pouches. It is supplied by the ventral branches of the first to fourth cervical nerves in the horse and the first to sixth cervical nerves in other domestic species.

Muscles of the trunk (musculi trunci)

The trunk of an animal comprises the neck, the thorax, the abdomen, the rump and the tail. The head is attached to it cranially, the limbs on either side, the muscles of the trunk extend onto the head and the limbs, thus joining them to the trunk. In addition these muscles play an important role in the standing animal as well as during locomotion.

The muscles of the trunk can be grouped based on their topography as follows:

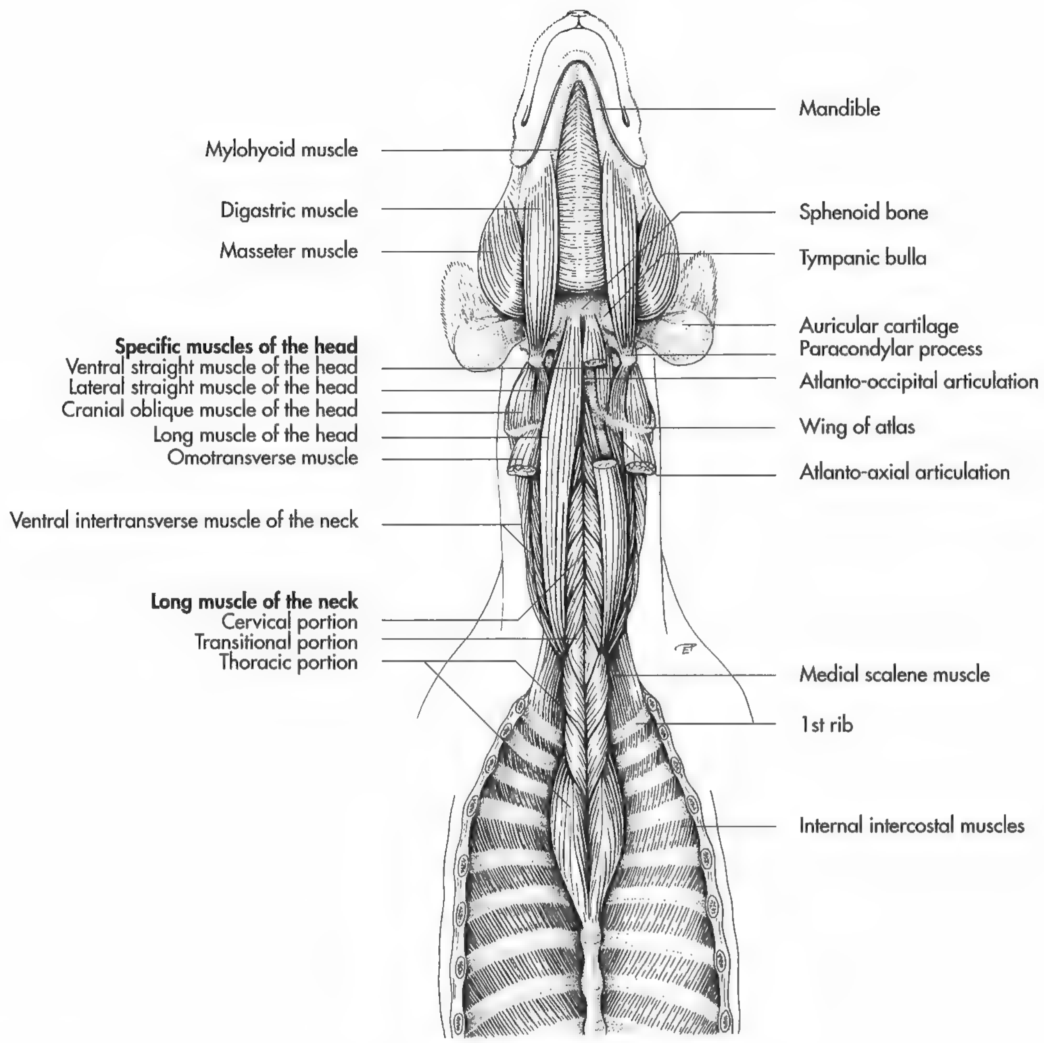

Fig. 2-7. Superficial muscle of the head and deep muscles of the neck of the dog (schematic, ventral aspect).

- Muscles of the neck (mm. colli),
- Muscles of the back (mm. dorsi),
- Muscles of the thoracic wall (mm. thoracis),
- Muscles of the abdominal wall (mm. abdominis) and
- Muscles of the tail (mm. caudae).

Muscles of the neck (mm. colli)

The muscles of the neck are situated on the dorsal and lateral side of the cervical column. Some of the muscles of the neck are associated with the hyoid apparatus. The most important muscles of this group are the **brachiocephalic muscle** with its various components and the **sternocephalic muscle.** Because of the important role they play in the movement of the thoracic limb, both muscles are described in Chapter 3 as part of the shoulder girdle musculature. In addition this group includes the following muscles:

- **Splenius muscle** (m. splenius):
  - Cervical portion (m. splenius cervicis),
  - Capital portion (m. splenius capitis).
- **Long muscle of the neck** (m. longus colli).

- **Scalene muscles** (mm. scaleni):
  - Ventral scalene muscle (m. scalenus ventralis),
  - Middle scalene muscle (m. scalenus medius),
  - Dorsal scalene muscle (m. scalenus dorsalis).

- **Muscles of the hyoid apparatus** (mm. hyoidei):
  - Specific muscles of the hyoid apparatus,
  - Long muscles of the hyoid apparatus,
  - Sternohyoid muscle (m. sternohyoideus),
  - Sternothyroid muscle (m. sternothyreoideus) and
  - Omohyoid muscle (m. omohyoideus).

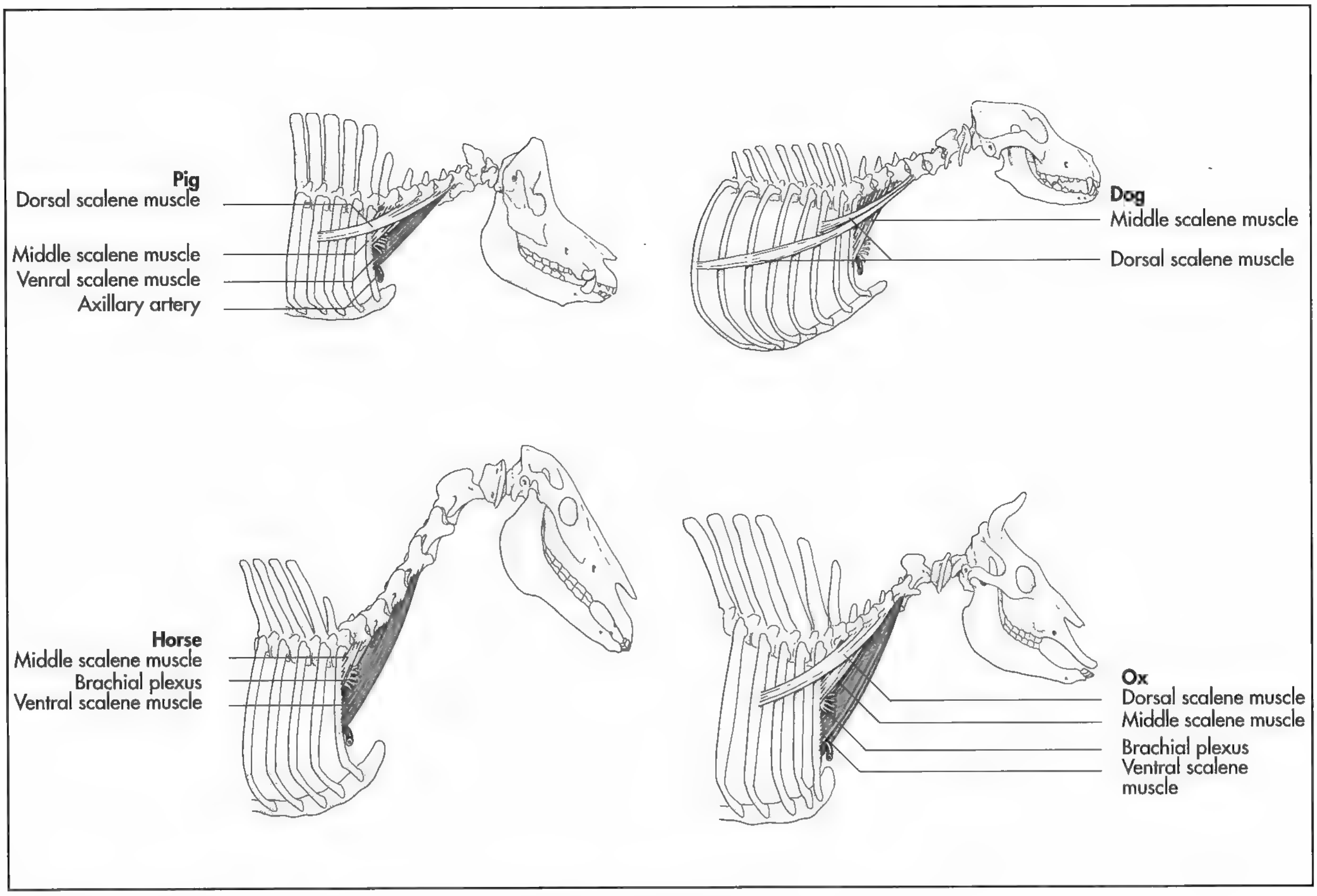

Fig. 2-8. The scaleni muscles of the domestic mammals (schematic) (Ellenberger and Baum, 1943).

The **splenius muscle** is a flat, elongated muscle on the dorsolateral aspect of the neck, extending from the withers to the occiput (Fig. 2-9). It lies below the superficial muscles of the neck and covers the longissimus muscle of the head, the semispinal muscle of the head and parts of the dorsal spinal muscle. It originates from the spinocostotransverse fascia and the nuchal ligament and in ruminants, directly from the spinous processes of the first four thoracic vertebrae as well. It is divided into a **capital** and a **cervical portion** (m. splenius capitis et cervicis), with the exception of carnivores in which the latter portion is absent. The cervical portion inserts on the transverse processes of the third to fifth cervical vertebrae, while the capital portion continues to the nuchal crest of the occiput or, in the horse, the mastoid process of the temporal bone. This muscle is especially well developed in the horse, in which it can be easily identified under the skin. It extends and raises the head and neck. Unilateral contraction draws the head and neck laterally. It plays an important role in maintaing balance during gallop.

The long muscle of the neck and the scalene muscles belong to a group of muscles, which depress and flex the neck downward. Some muscles of the shoulder girdle fulfil the same function and are described in Chapter 3.

The **long muscle of the neck** lies on the ventral aspect of the cervical and first few thoracic vertebrae. It extends from the first thoracic vertebrae to the atlas and finds its cranial continuation in the long muscle of the head. The thoracic portion attaches to the bodies of the last two cervical vertebrae up to the sixth thoracic vertebra. The cervical part originates, with separate muscle bundles, from the transverse processes of the third to seventh cervical vertebrae and runs craniomedially to insert on the bodies of the more cranial cervical vertebrae near the midline. It draws the neck downward.

The **scalene muscles** comprise two or three separate muscles, depending on the species. While all three muscles, the dorsal, ventral and middle scalene muscles are present in the pig and ruminants, the dorsal muscle is absent in the horse and the ventral muscle is absent in carnivores. All three portions extend from the transverse processes of the third to seventh cervical vertebrae to the lateral surface of the first and the third to the eighth ribs, again varying among the different species (Fig. 2-8).

The **ventral** and **middle scalene muscles** originate from the first rib and are divided by the brachial plexus (plexus brachialis). This division does not exist in carnivores due to the more ventral location of the brachial plexus in these animals.

The **dorsal scalene muscle** originates from the third rib in the pig, the fourth or fifth rib in ruminants and with two heads from the third to fifth ribs in carnivores. It inserts to the third to sixth cervical vertebrae in all domestic mammals, except in the horse, in which this muscle is absent.

Tab. 2-5. Specific muscles of the head.

Name Innervation	Origin	Insertion	Action
Major dorsal straight muscle of the head Dorsal branch of 1st cervical nerve	Spinous process of the axis	Nuchal crest	Extension of the atlanto-occipital joint
Minor dorsal straight muscle of the head Dorsal branch of 1st cervical nerve	Dorsally on the atlas	Dorsally of the magnum foramen	Extension of the atlanto-occipital joint
Lateral straight muscle of the head Ventral branch of 1st cervical nerve	Ventrally on the atlas	Paracondylar process	Flexion of the atlanto-occipital joint
Ventral straight muscle of the head Ventral branch of 1st cervical nerve	Ventrally on the atlas	Base of the skull	Flexion of the atlanto-occipital joint
Cranial oblique muscle of the head Dorsal branch of 1st cervical nerve	Wings of the atlas	Nuchal crest	Extends and draws head to the side
Caudal oblique muscle of the head Dorsal branch of 2nd cervical nerve	Spinous process of the axis	Wings of the atlas	Rotation of the head and fixation of the atlantooccipital joint
Long muscle of the head Ventral branches of cervical nerves	Transverse processes of the 2nd–6th cervical vertebra	Base of the skull	Flexes and draws head and cranial parts of the neck to the side

Tab. 2-6. Superficial muscles of the neck.

Name Innervation	Origin	Insertion	Action
Splenius			
– **Cervical portion**	Spinocostotransverse fascia, nuchal ligament, spinous processes of the thoracic vertebrae	Transverse processes of the 3rd–5th cervical vertebra	Extends and draws head and neck to the side
– **Capital portion** Dorsal branches of the cervical and thoracic nerves		Occipital bone, Mastoid process	
Long muscle of the neck Ventral branches of the cervical nerves	5th–6th thoracic vertebrae	1st cervical vertebra	Flexion of the neck
Scalene muscle Ventral branches of the 5th–8th cervical and 1st–2nd thoracic nerves			
Middle scalene muscle	1st rib	Transverse processes of the 7th–3rd cervical vertebrae	Fixation of the neck, draws neck downwards and bends it sideways; supports inspiration
Ventral scalene muscle excl. carnivores	1st rib	7th cervical vertebra	Fixation of the neck, draws neck downwards and bends it sideways; supports inspiration
Dorsal scalene muscle excl. horse	3rd–8th rib	Transverse processes of the 6th–3rd cervical vertebra	Fixation of the neck, draws neck downwards and bends it sideways; supports inspiration

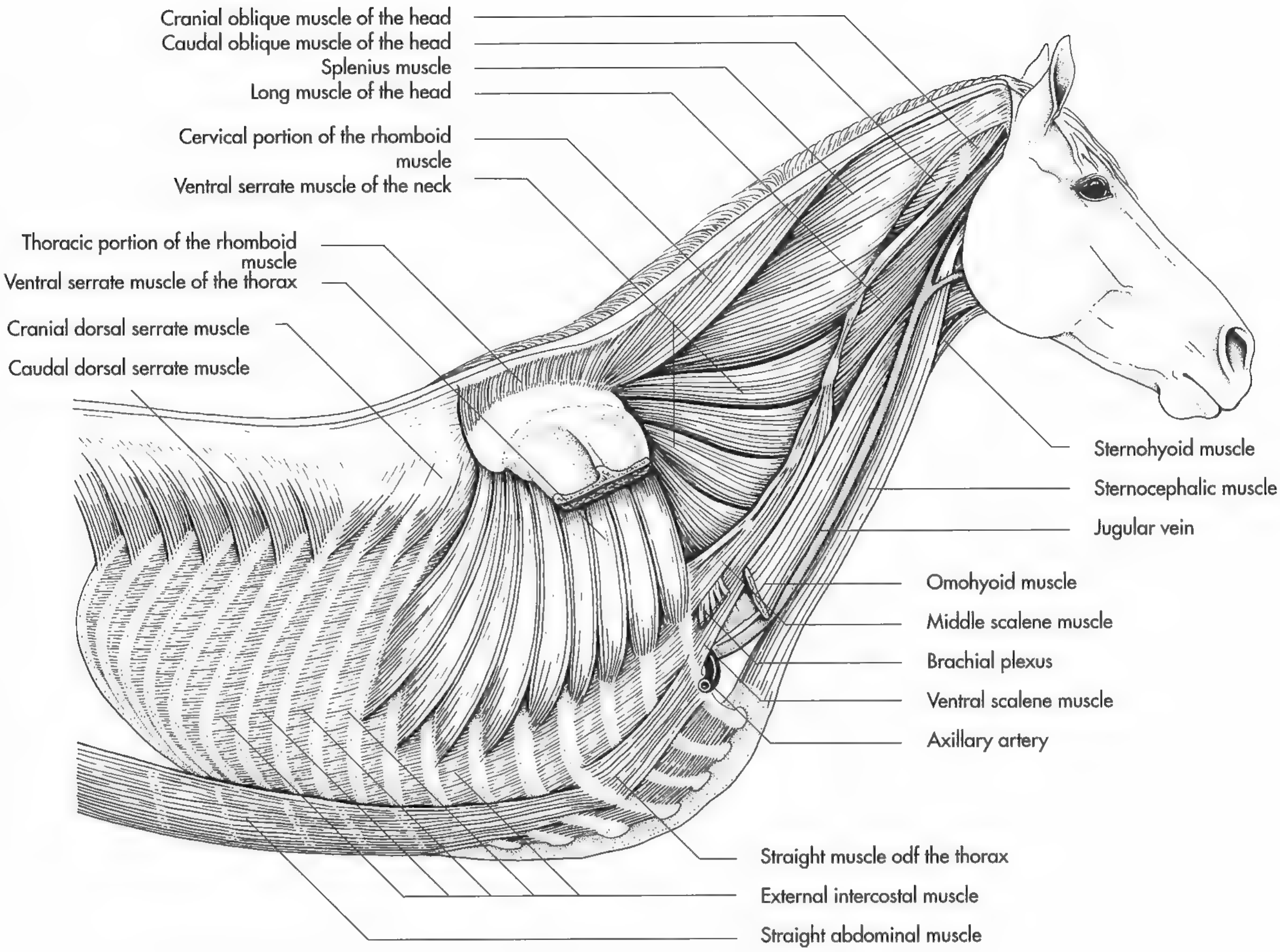

Fig. 2-9. Superficial muscles of the trunk of the horse (schematic) (Ghetie, 1954).

The **hyoid muscles** comprise all the muscles which are associated with the hyoid apparatus. The specific muscles of the hyoid apparatus include the **stylohyoid muscle** (m. stylohyoideus) of the basihyoid bone, the **mylohyoid muscle** (m. mylohyoideus), which is described earlier in this chapter as part of the mandibular muscles, the **geniohyoid muscle** (m. geniohyoideus), extending between the mandible and the hyoid bone, and several other muscles, such as the **thyrohyoid muscle** (m. thyrohyoideus), the **occipitohyoid muscle** (m. occipitohyoideus), **ceratohyoid muscle** (m. ceratohyoideus) and the **transverse hyoid muscle** (m. hyoideus transversus).

These muscles are described in detail together with the rest of the hyoid apparatus in the second volume.

The **long hyoid muscles** lie ventral and lateral to the trachea and are therefore topographically part of the musclulature of the neck. Functionally, however, they act as auxillary muscles of the tongue, since they insert on the basihyoid and the larynx. They originate from the manubrium of the sternum and are covered to a large extent by the brachiocephalic and sternocephalic muscles. They draw the hyoid bone and thus the tongue caudally.

The **sternohyoid muscle** is a strong strap-like muscle, which originates from the manubrium of the sternum and the first rib (carnivores) and inserts on the basihyoid bone (Fig. 2-6). It meets its contralateral partner on the midline of the neck and they extend cranially, covering the ventral surface of the trachea. Its caudal half is fused to the **sternothyroid muscle.**

The **sternothyroid muscle** separates from the sternohyoideus in the middle of the neck and inserts on the thyroid cartilage of the larynx (Fig. 2-6).

The **omohyoid muscle** is most developed in the horse and is absent in carnivores (Fig. 2-6). It originates from the subscapular fascia, close to the shoulder joint in the horse and from the deep fascia of the neck in ruminants and inserts on the basihyoid bone. In the horse, the omohyoid muscle unites

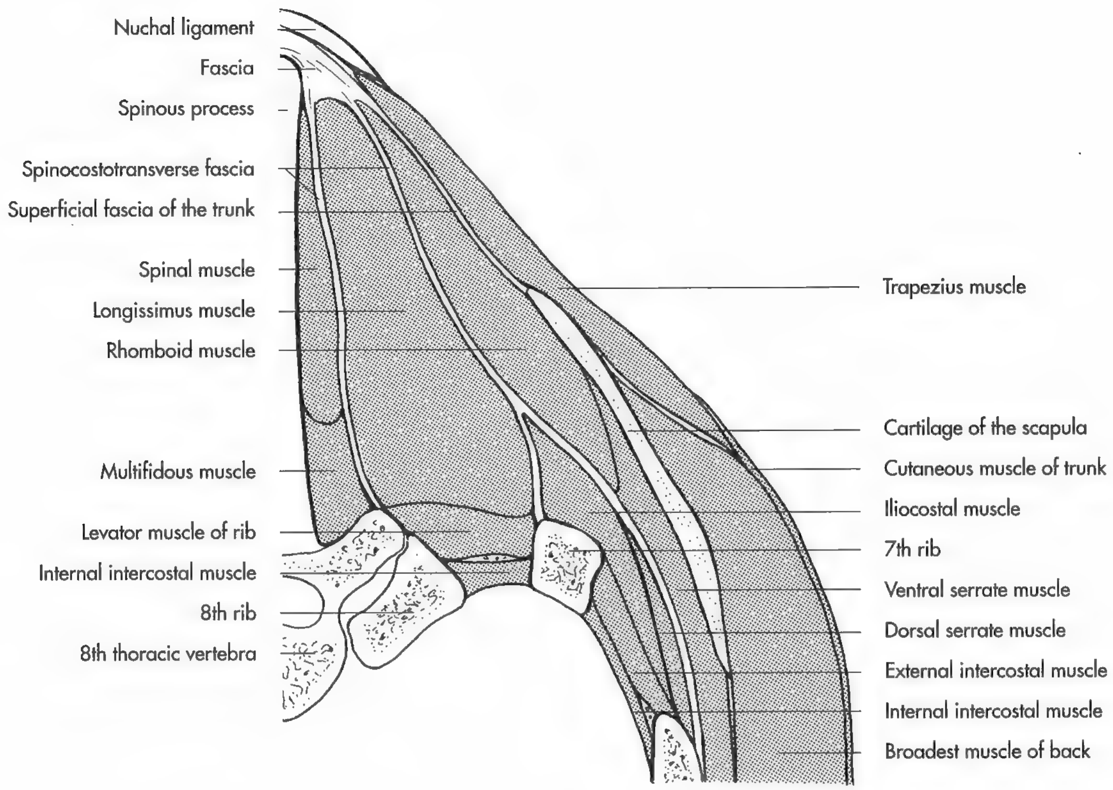

Fig. 2-10. Muscles of the back, cross-section at the level of the eight thoracic vertebra (schematic) (Ellenberger and Baum, 1943).

with the corresponding muscle of the opposite side midway up the neck and inserts together with the sternohyoid muscle on the lingual process of the hyoid bone. In the cranial half of the neck it is positioned between the external jugular vein and the common carotid artery, thus providing some protection for the latter during intravenous injection.

Muscles of the back (mm. dorsi)

The muscles of the back include all muscles which are situated along the cervical, thoracic and lumbar vertebral column. They arise either from the bodies or processes of the vertebrae or from fascia. From a topographic point of view, the muscles of the back are arranged in two layers, functionally these groups complement each other.

The muscles of the **superficial layer** lie on the lateral side of the rump and are innervated by the ventral branches of the spinal nerves. This layer also includes part of the shoulder girdle musculature, which joins the thoracic limb to the rump:

- Trapezius muscle (m. trapezius),
- Omotransverse muscle (m. omotransversarius),
- Broadest muscle of the back (m. latissimus dorsi),
- Rhomboid muscle (m. rhomboideus) and
- Cervical portion of the serrate muscle (m. serratus ventralis cervicis).

These muscles extend from the rump, the ribs or regional fasciae to the skeleton of the shoulder girdle and are described in detail in Chapter 3.

Based on their embryologic origin and their innervation, by the ventral branches of the spinal nerves, some muscles of the thoracic wall (mm. serrati dorsales) are classified in this group, but are described according to their function as part of the respiratory muscles later in this chapter (Fig. 2-9).

The **deep layer** of the muscles of the back are dorsal to the transverse processes of the vertebrae and supplied by the dorsal branches of the spinal nerves. Some muscles of this group are elongated individual muscles **(long muscles of the back),** which extend along the vertebral column, other muscles are short and small **(short muscles of the back),** extending from one segement to the next. Functionally these muscles elevate, rotate and dorsally, ventrally and laterally flex the vertebral column. Cranially the muscles of these group are rather delicate muscle bundles, thus increasing the mobility of the head and neck region, especially in carnivores, whereas in the lumbar region this group comprises rather strong muscles, which provide stabilization of this part of the vertebral column.

The **deep layer** of the muscles of the back can be further divided into a **lateral** and **medial system.** Both groups form two strong muscular columns, which occupy the space between the spinous and transverse processes of the cervical, thoracic and lumbar vertebrae. Large parts of these groups can be summarized as erector muscles of the spine (mm. erectores spinae),

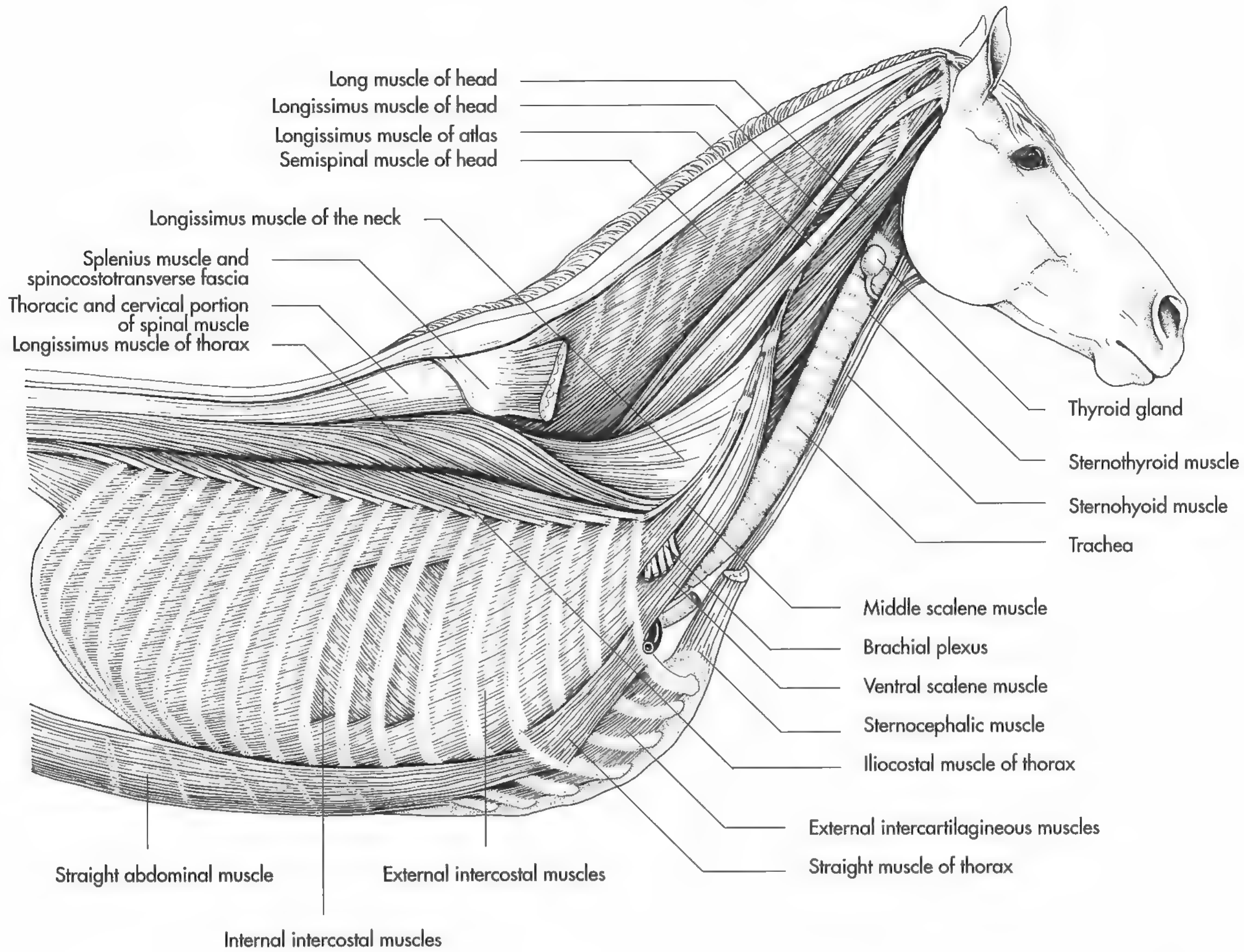

Fig. 2-11. Superficial and middle layers of the trunk musculature of the horse (schematic) (Ghetie, 1954).

a term which is much more appropriate in the cat and dog than in ruminants and the horse, in which the vertebral column is somewhat more rigid. Since the erector spinae muscles vary considerably in location and function it is difficult to group them systematically.

This system is complemented by the **transversospinal muscles** (mm. transversospinales), **interspinal muscles (mm. interspinales)** and the **intertransverse muscles** (mm. intertransversarii), which represent the short muscles of the back.

Long muscles of the neck and back

The **lateral group of muscles** consists of longitudinal muscle masses, which cross several consecutive vertebrae. These elongated muscle bellies are the result of various fusions of the primary segmental muscles of the neck and back. Their original segmental pattern is still present in that the different segments are innervated by the dorsal branches of the corresponding segmental nerves. They originate from the sacrum, the ilium and by means of tendons or small muscular digitations from the vertebrae of the trunk and insert on the ribs or the head **(sacrospinal system).**

In the neck region, extending from the withers to the occiput, the muscles of the lateral group are covered superficially by the muscles of the neck. The following muscles of the trunk are assigned to the lateral system (Fig. 2-11, Table 2-7):

- **Iliocostal muscle** (m. iliocostalis):
  - Lumbar portion (m. iliocostalis lumborum),
  - Thoracic portion (m. iliocostalis thoracis),
- **Longissimus muscle** (m. longissimus):
  - Lumbar portion (m. longissimus lumborum),
  - Thoracic portion (m. longissimus thoracis),
  - Cervical portion (m. longissimus cervicis),
  - Atlas portion (m. longissimus atlantis) and
  - Capital portion (m. longissimus capitis).

The **iliocostal muscle** is a slim, elongated muscle, which is composed of a series of overlapping fascicles (Fig. 2-11). Its fibres are orientated in a cranioventral direction and span several vertebral segments. It originates from the crest of the ili-

Tab. 2-7. Long muscles of the neck and back – lateral system.

Name Innervation	Origin	Insertion	Action
Iliocostal muscle Dorsal branches of the thoracic and lumbar nerves			
– Iliocostal muscle lumbar protion	Iliac crest	Caudal border of the last rib	Fixation of the loin and ribs
– Iliocostal muscle thoracic portion	Transverse processes of the lumbar column	Caudal borders of the ribs	Draws the vertebral column sideways
– Iliocostal muscle cervical portion	Transverse processes of the cranial thoracic vertebrae	Transverse processes of the 7th cervical vertebra	Bends the vertebral column sideways
Longissimus muscle Dorsal branches of the cervical, thoracic and lumbar nerves			
– Longissimus muscle lumbar and thoracic portion	Spinous processes of the sacral, lumbar and thoracic vertebrae; ilium	Articular, mamillary and transverse processes of the thoracic column and proximal on the ribs	Fixation and extension of the vertebral column, raises cranial part of the body
– Longissimus muscle cervical portion	Transverse processes of the first 5–8 thoracic vertebrae	Transverse processes of the 3rd–7th cervical vertebrae	Raises and bends the neck laterally
– Longissimus muscle capital and atlas portion	Transverse processes of the first thoracic and last cervical vertebra	Wing of the atlas and mastoid part of the temporal bone	Raises and bends the head sideways; turns the head

um, the transverse processes of the lumbar vertebrae and the fascial sheet ("Bogorozky tendon"), which separates the iliocostal muscles from the longissimus. It extends cranially as far as the cervical vertebral column and lies next to the broadest muscle of the back on the dorsal side of the angle of the ribs. It ends with one common tendon of insertion on the last cervical vertebra. Topographically the iliocostal muscle can be divided into a **lumbar** and **thoracic portion.**

The **lumbar portion** of the iliocostal muscle is well distinguishable as an independent muscle in carnivores only, while in the pigs and the horse it is fused with the lumbar portion of the broadest muscle of the back. In carnivores it attaches to the ends of the transverse processes of the lumbar vertebrae and inserts with fleshy serrations on the 11th to 13th rib. In ruminants the tendon of insertion attaches to the last rib only. In the horse a very short lumbar portion inserts on the transverse processes of the middle lumbar vertebrae.

The **thoracic portion** (Fig. 2-11) lies lateral to the broadest muscle of the back and forms the cranial continuation of the lumbar portion of the iliocostal muscle. Its individual bundles originate with glistening tendons from the lumbar portion and extend craniolaterally spanning two to four intercostal spaces each.

After forming a common muscle belly it inserts, with terminal serrations, on the caudal side of the first (tuberositas musculi iliocostalis) to the 12th ribs and to the transverse process of the seventh cervical vertebra (carnivores). In the horse they insert on the caudal surface of the first to 15th rib, with medial, deeper tendons of insertion to the cranial surface of the fourth to 18th rib and to the transverse process of the seventh cervical vertebra.

The iliocostalis stabilises the lumbar and thoracic parts of the vertebral column. In carnivores it assists in the forward propulsion of the body when running. It also aids in expiration by pulling the ribs caudally.

The **longissimus muscle** forms a major part of the paraxial musculature of the trunk (Fig. 2-11). It extends over the entire length of the back and neck from the pelvis to the head, thus forming the longest muscle of the body. Its original segmental arrangement is still reflected in the numerous individual attachments of its segmental muscle bundles. Its overlapping fascicles arise from the sacrum, ilium, the mamillary and spi-

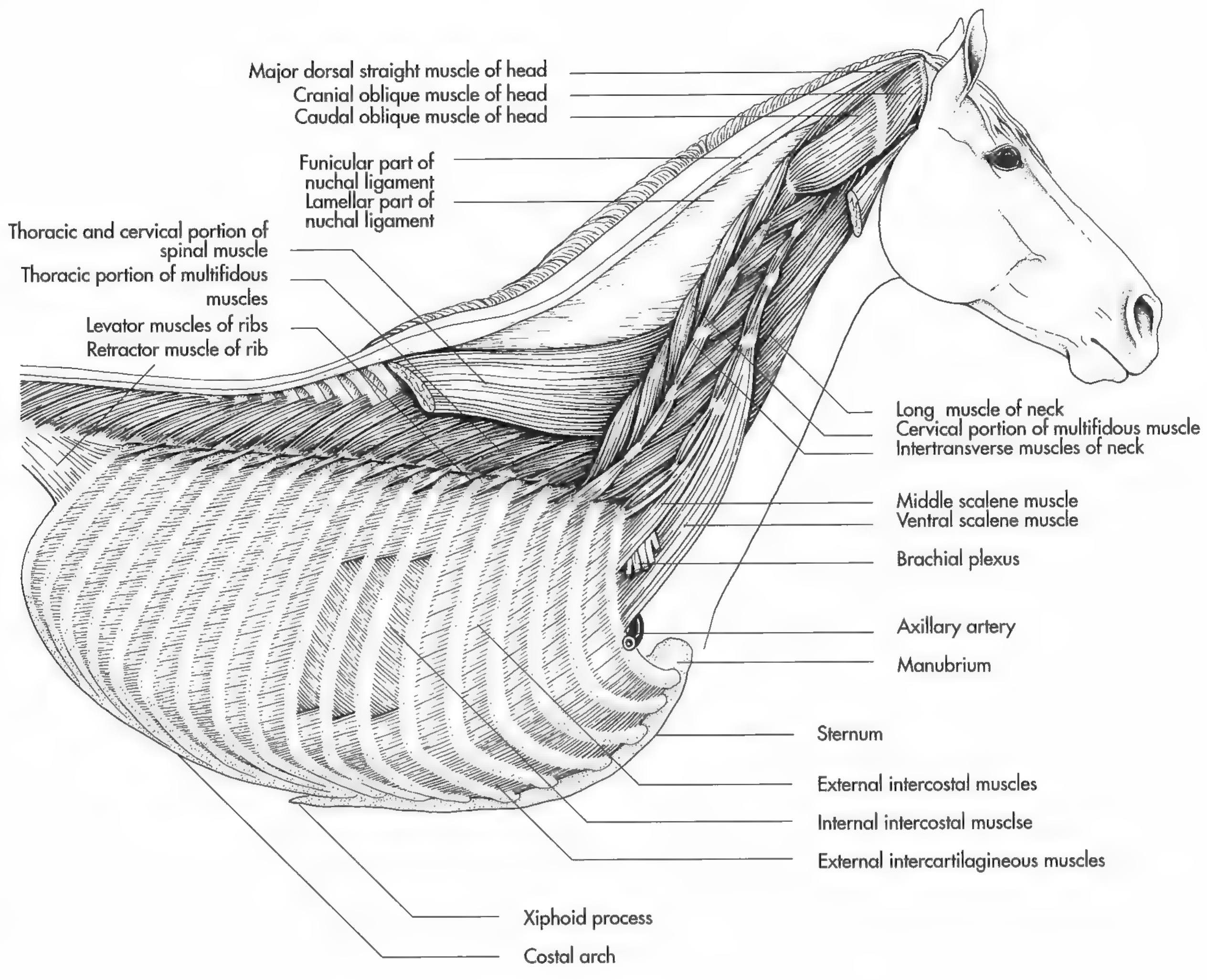

Fig. 2-12. Deep layer of the trunk musculature of the horse (schematic) (Ellenberger and Baum, 1943).

nous process of the thoracic and lumbar vertebrae and run cranioventrally and laterally to insert with several tendons on the mamillary and spinous processes and the longissimus tuberosities of the ribs (tuberositates musculi longissimi).

The longissimus muscle is the thickest in the lumbar region, where it is covered by a the thoracolumbar fascia, from which it partly originates. It gradually narrows in the thoracic region.

The muscles can be divided into several distinct parts based on location and points of insertion. The **lumbar portion** (m. longissimus lumborum) and **thoracic portion** (m. longissimus thoracis) extend from the pelvis to the seventh cervical vertebrae. They occupy the space between the spinous processes medially and the transverse processes and the dorsal ends of the ribs ventrally. Laterally it is covered by the iliocostalis muscle. It continues cranially with a **cervical portion,** which fans out between the transverse processes of the first five to eight thoracic and the last cervical vertebrae. The longissimus muscle of the atlas and the longissimus muscle of the head originate from the transverse processes of the second and third thoracic vertebrae and last four to five cervical vertebrae, run cranially deep to the cervical portion and end on the wing of the atlas and the mastoid process of the occiput.

The longissimus muscles extend and stabilize the vertebral column. It reaches greatest its extension during the swing phase of the hindlimb. It plays an important role in transmitting the thrust of the hindlimbs to the back during the swing phase of progression. It also raises the cranial portion of the body, when the hindlimbs are fixed on the ground (rearing) and raises the caudal portion of the body at the same time flexing the back ventrally, when the forelimbs are fixed (kicking). Unilateral contraction flexes the vertebral column laterally and rotates the head.

In well trained, muscular horses this muscle can extend beyond the dorsal ends of the spinous processes on both sides, thus resulting in a groove over these processes.

The **medial system of muscles** forms the deep layer of the neck and back musculature. This group still shows their embryological segmental pattern. It consists of a number of

Tab. 2-8. Long muscles of the neck and back – medial system.

Name Innervation	Origin	Insertion	Action
Thoracic and cervical part of the spinal muscle (pig/horse), Dorsal branches of the cervical, thoracic and lumbar nerves	Extending across the spinous processes of one or more vertebrae		Fixation of the back and neck
Thoracic and cervical part of the spinal and semispinal muscle (carnivores/ruminants) Dorsal branches of the cervical, thoracic and lumbar nerves	Spinous processes, mamillary- and tansverse processes of the first lumbar and last thoracic vertebra	Spinous processes of the 1st–6th thoracic and 6th/7th cervical vertebra	Fixation and extention of the back, levator of the neck, unilaterally: bends back and neck sidewayes
Semispinal muscle of the head Dorsal branches of the cervical nerves	Spinocostotransverse fascia,- transverse processes of the first 5–8 thoracic vertebrae, articular processes of the 2nd–7th cervical vertebra	Occipital squama	Raises and bends head sideways
Multifidous muscles Dorsal branches of the cervical, thoracic and lumbar nerves	Articular and mamillary processes, from the sacrum to the 3rd cervical process	Spinous processes and dorsal arches of the foregoing vertebra, in the thoracic region also the transverse processes of the vertebrae	Fixation and rotation of the vertebral column, levator of the neck
Rotator muscles Dorsal branches of the thoracic nerves	Transverse processes	Spinous processes	Fixation and rotation of the vertebral column

fascicles, which extend between two adjacent vertebrae vertebra. They lie directly over the skeleton, occupying the space between the spinous processes, the vertebral arches and the transverse processes.

The muscle bundles of the medial group extend either between spinous processes **(spinal system)** or from spinous process to the transverse process of adjacent vertebrae **(transversospinal system).** Its fibres are orientated in a sagittal direction or from caudo-ventro-lateral to a cranio-dorso-medial direction, thus showing the opposing fibres of the lateral system.

The muscles of the medial system are innervated by the dorsal branches (rami dorsales) of the spinal nerves.

Some of the muscles of this system extend into a cranial grup, termed "specific muscles of the head", which describes their function, as opposed to their heterogenous embryologic origin, these muscles were described earlier in this chapter.

Although, the differentiation between the muscles of the medial group is less distinct in the domestic mammals than in man, it varies between the different species. They can be divided topographically and functionally in the following muscle complexes:

- **Spinal muscle** (m. spinalis)
  - Thoracic portion (m. spinalis thoracis),
  - Cervical portion (m. spinalis cervicis),
- **Transversospinal muscles** (mm. transversospinales),
- **Thoracic and cervical semispinal muscle** (m. semispinalis thoracis et cervicis):
  - Semispinal muscle of the head (m. semispinalis capitis),
  - Biventer muscle of the neck (m. biventer cervicis),
  - Complexus muscle (m. complexus),
- **Multifidous muscles** (mm. multifidi) and
- **Rotator muscles** (mm. rotatores).

These muscles form three muscular bands, with the multifidous and rotator muscles forming the deepest layer and the spinal muscles extending between the latter and the longissimus muscle.

The **spinal muscle** passes between the spinous processes of adjacent vertebrae. In the pig and horse, they form a common muscle belly, which bridges several segments and is therefore termed **thoracic and cervical spinal muscle.** It originates from the spinous processes of the first six lumbar vertebrae and last six thoracic vertebrae, passes cranially in a horizontal direction to the spinous processes of the more cranial thoracic vertebrae and the seventh to third cervical vertebrae (Fig. 2-12).

In ruminants and carnivores the thoracic and cervical spinal muscle receives additional muscular strands from the mamillary and transverse processes of some vertebrae (m. transversospinalis).

For this reason it is designated by a compound name, **thoracic and cervical spinal and semispinal muscle.** This

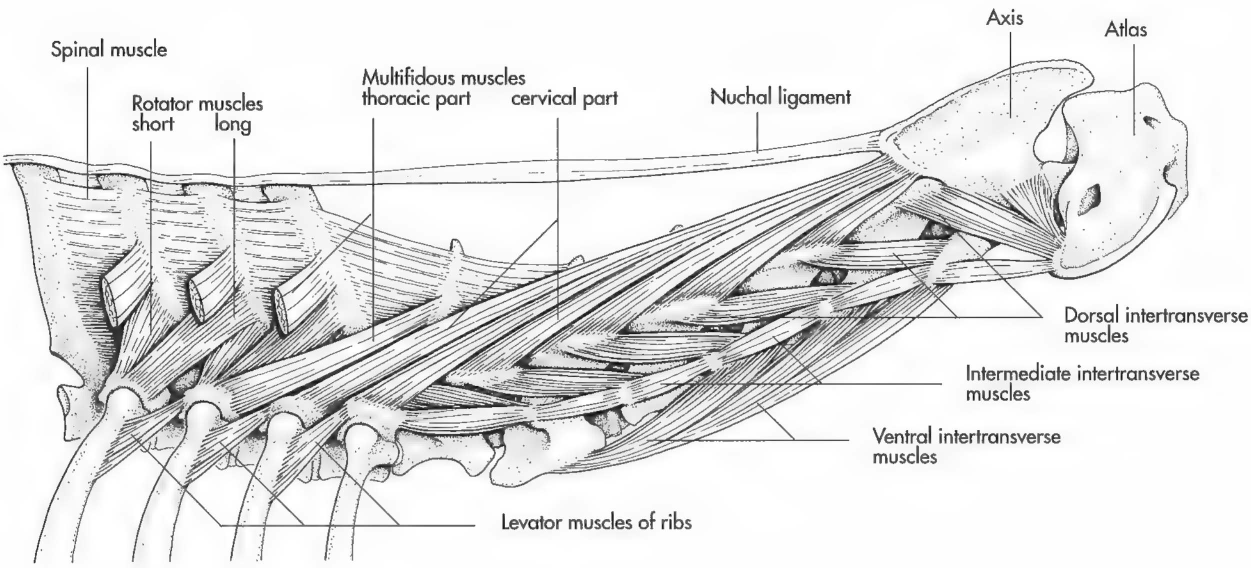

Fig. 2-13. Deep musculature of the neck of the dog (schematic).

muscle consist of numerous individual muscle bundles, which lie in the region of the lumbar, thoracic and cervical vertebrae. The thoracic and lumbar spinal and semispinal muscles stabilise the back and elevate the neck, when acting together. Contracting unilaterally they flex the back and neck laterally.

These muscles find a direct continuation to the neck and head in the **semispinal muscle of the head.** This strong muscle plate occupies the space between the occiput, the cervical vertebrae and the nuchal ligament, covered on its lateral aspect by the longissimus and the splenius muscles. It can be divided in the dorsomedially located **biventer muscle of the neck** and the ventrolateral **complexus muscle.**

The semispinal muscle of the head raises the head, when acting bilaterally and flexes the head and neck laterally, when acting unilaterally.

The **multifidous muscles** represent the deepest layer of the medial system of the long muscles of the neck and back (Fig. 2-13). It is composed of numerous individual portions and arranged in overlapping segments, which extend from the the articular and mamillary processes, and in the thoracic region from the transverse processes, to the spinous processes of the preceding vertebrae. They extend from the lumbar vertebrae to the cervical vertebral column and can include up to five segments in the thoracic region. Cranially it unites with the oblique muscle of the head and caudally with the musculature of the tail.

It is responsible for the coordination of the long muscles of the neck and back.

The **rotator muscles** are only present in parts of the thoracic vertebral column to which rotational movements are possible (first to tenth thoracic vertebra in carnivores and pigs, first to 12th in ruminants and 16th in horses). They comprise short muscle bundles, which unite the transverse processes with the spinous process of the adjacent vertebra (carnivores) and long muscles, which pass over two segments in all domestic animals (Fig. 2-13).

Short muscles of the neck and back

The lateral and medial systems of the long muscles of the neck and back is complemented by short intersegmental muscle bands. They are divided into two groups:

- Interspinal muscles (mm. interspinales) and
- Intertransverse muscles (mm. intertransversarii).

The muscles of the **intertransversal system** extend between the transverse processes and the muscles of the spinal system between the spinous processes of the vertebrae (Table 2-9).

The **interspinal muscles** consist of short muscular (carnivores) or tendinous (ungulates) bands (ligamenta interspinalia) between adjacent spinous processes of the caudal cervical, the thoracic and first few lumbar vertebrae. They support the ventroflexion of the vertebral column.

The **intertransversal muscles** extend between the transverse processes, or between the transverse and articular processes or between the mamillary and accessory processes. In the dog and horse they are separated into a **lumbar group** (mm. intertransversarii lumborum) and a **thoracic group** (mm. intertransversaii thoracis), which run between the mamillary and transverse processes of the lumbar, and thoracic vertebrae and a **cervical group** (mm. intertransversarii dorsales et ventrales cervicis) between the transverse processes of the cervical vertebrae (Fig. 2-13). The intertransversal muscles

Tab. 2-9. Short muscles of the neck and back.

Name Innervation	Origin	Insertion	Action
Interspinal muscles Dorsal branches of the thoracic nerves Dorsal branches of the lumbar nerves	Spinous processes	Spinous processes	Fixation and ventral flexion of the thoracic and lumbar vertebrae
Intertransverse muscles Dorsal branches of the cervical, thoracic and lumbar nerves	Transverse processes Mamillary processes	Transverse processes Articular processes	Fixation and lateral flexion of the cervical and lumbar vertebral column

assist in coordinating the movements of the vertebral column. It also stabilises and flexes it laterally.

Muscles of the thoracic wall (mm. thoracis)

The muscles of the thoracic wall comprise two groups, the muscles of the **deep and superficial layer of the shoulder girdle** and **muscles of respiration**. The shoulder girdle musculature includes the superficial and deep pectoral muscles (m. pectoralis superficialis, m. pectoralis profundus), the subclavian muscle (m. subclavius) and the thoracic portion of the ventral serrate muscle (m. serratus ventralis), which cover the muscles of the trunk on the lateral aspect of the thorax. Functionally they are part of the shoulder girdle and are therefore presented in detail in Chapter 3 as part of the thoracic limb.

Respiratory muscles

All respiratory muscles are attached to the **skeleton of the thorax:** either to the ribs or the costal cartilages. They comprise muscles, which occupy the spaces between the ribs (mm. intercostales) and small muscles, which lie on the lateral surface of the ribs (Table 2-10). The most important respiratory muscle is the **diaphragm** (diaphragma), which separates the thoracic and abdominal cavities.

Functionally the respiratory muscles can be divided into **inspiratory muscles,** which enlarge the thoracic cavity, allowing air flow into the lungs and **expiratory muscles,** which diminish the volume of the thoracic cavity, expelling air from the lungs and airways. The inspiratory muscles rotate the ribs craniolaterally, whereas the expiratory muscles rotate them caudomedially.

Similar to the muscles of the back, the intercostal muscles have an embryologically segmental arrangement, which is reflected by their nerve supply from the segmental intercostal nerves.

This group comprises the following muscles:

- **Dorsal serrate muscles** (mm. serrati dorsales):
  - Cranial dorsal serrate muscle (m. serratus dorsalis cranialis),
  - Caudal dorsal serrate muscle (m. serratus dorsalis caudalis),
- **Intercostal muscles** (mm. intercostales):
  - External intercostal muscles (mm. intercostales externi),
  - Internal intercostal muscles (mm. intercostales interni),
  - Subcostal muscles (mm. subcostales),
  - Retractor muscle of the ribs (m. retractor costae),
- **Levator muscles of the ribs** (mm. levatores costarum),
- **Transverse thoracic muscle** (m. transversus thoracis),
- **Straight thoracic muscle** (m. rectus thoracis),
- **Diaphragm** (diaphragma):
  - Lumbar portion (pars lumbalis),
  - Costal portion (pars costalis),
  - Sternal portion (pars sternalis) and
  - Central tendon (centrum tendineum).

The **dorsal serrate muscles** originate with an aponeurosis from the spino-costo-transversal fascia, the supraspinal ligament and from the thoracolumbar fascia caudally. They attach by a series of individual digitations to the ribs lateral to the iliocostal muscles. Based on the direction of their fibres they can be divided into a **cranial portion** and a **caudal portion** (Fig. 2-9).

The cranial portion pulls the ribs caudoventrally and rotates them outward during contraction, thus acting as an inspiratory muscle. In carnivores it originates from the first six to eight thoracic vertebrae and the thoracolumbar fascia and inserts with single slips to the cranial and lateral aspect of the third to 10th rib, in the horse to the third to 12th rib.

The fibres of the caudal portion slope cranioventrally, showing an antagonistic direction to the ones of the cranial portion. The slips of the caudal portion rotate the ribs backward and inward, thus assisting exspiration.

In the dog and cat the caudal portion originates from the thoracolumbar fascia and inserts on the 9th to 13th ribs in all species except the horse, where the insertions are on the caudal side of the 12th to 18th ribs.

The **intercostal muscles** occupy the spaces between the ribs and comprise a minimum of two layers, the deeper **internal intercostal muscles** and the more superficial **external intercostal muscles** (Fig. 2-12). The fibres of the internal intercostal muscles run from the cranial aspect of one rib to the caudal aspect of the preceding rib in a cranioventral direction. These muscles lie lateral to the intercostal nerve and assist expiration. The fibres of the external intercostal muscles are ori-

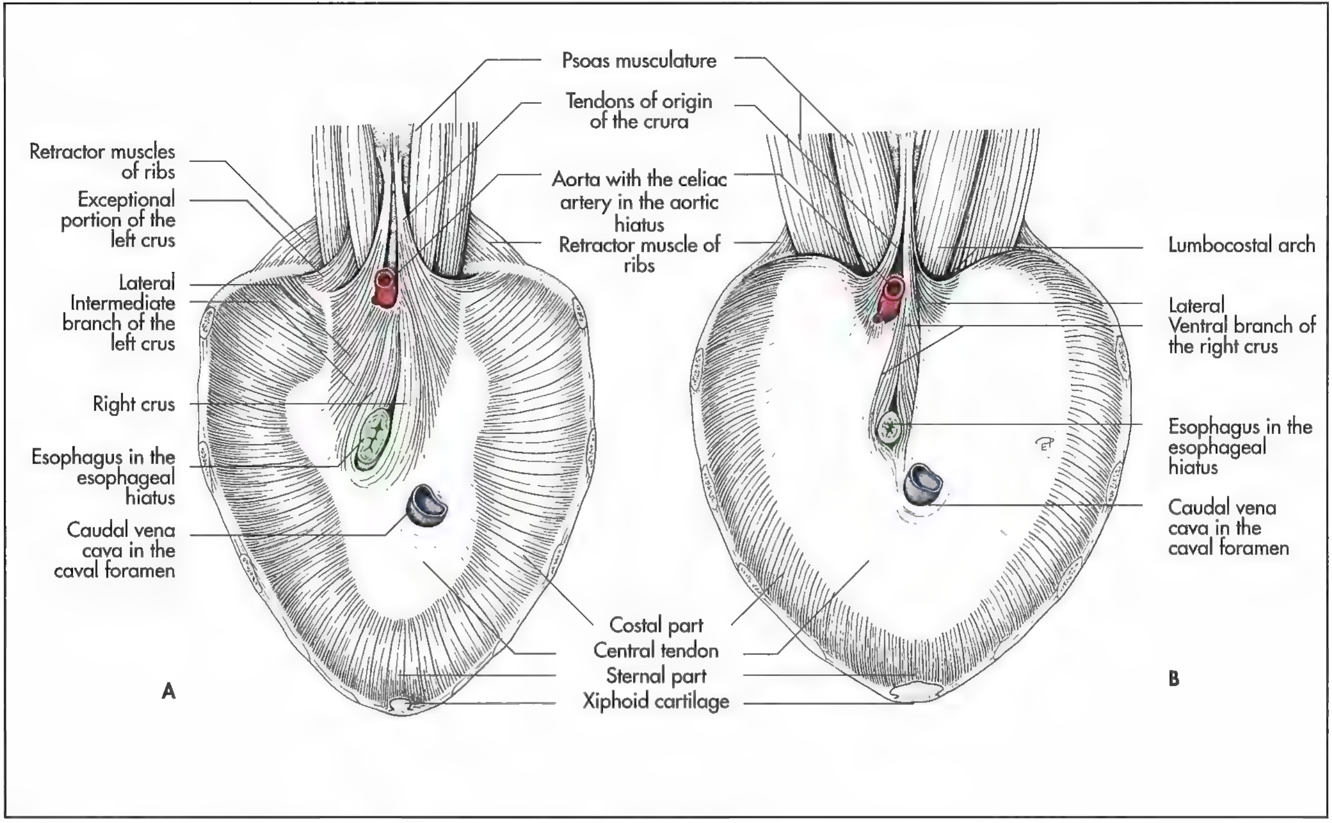

Fig. 2-14. Diaphragm of the dog **(A)** and horse **(B)** (schematic, caudal aspect).

entated perpendicular to the ones of the internal layer, thus bridging the individual intercostal spaces in a caudoventral direction, and acting as inspiratory muscles. The external intercostal muscles occupy the intercostal spaces from the vertebral column to the costochondral junctions, but do not extend as far as the sternum.

The **intercartilagenous muscles** are direct continuations of the intercostal muscles into the interchondral spaces.

The **subcostal muscles** are located deep to the internal intercostal muscles, medial to the intercostal nerves at the vertebral end of the last rib. They form two to three distinct muscle bundles in carnivores. These muscles and the retractor muscles of the ribs, which extend from the transverse processes of the cranial lumbar vertebrae and the thoracolumbar fascia to the last rib, act as expiratory muscles.

The **levator muscles of the ribs** constitute a series of small muscles, which are hardly distinguishable from the external intercostal muscle. (Fig. 2-13). They originate from the transverse and mammilary processes of all but the last thoracic vertebrae, pass caudoventrally to the angle of the adjacent ribs to insert on the cranial border of the second to the last rib. They are covered by the iliocostal and longissimus muscles of the back and are innervated by the dorsal branches of the thoracic nerves. The muscle of this group act as inspirators.

The **transverse muscle of the thorax** is a triangular sheet, lying on the inside of the sternum and the sternal costal cartilages. It originates from the sternal ligament (ligamentum sterni) and inserts to the costochondral junctions of the second to the eighth ribs. It pulls the ribs inward when contracting, thus assisting expiration.

The **straight muscle of the thorax** is a flat rectangular muscle covering the lateral aspect of the first three to four ribs (Fig. 2-11). It runs caudoventrally from its origin on the first rib to end in a broad tendon of insertion which blends with the aponeurosis of the straight abdominal muscle. It acts as an inspiratory muscle.

The **diaphragm** is a dome-shaped musculotendineous plate, which separates the thoracic and abdominal cavities (Fig. 2-14) and is present in all mammals. Its convex cranial side projects far into the thoracic cavity, so that the abdominal cavity has a large intrathoracic part. The point of maximum convexity is named the **vertex** or **cupula of the diaphragm** (cupula diaphragmatis).

On the thoracic side the diaphragm is covered by the **endothoracic fascia** (fascia endothoracica) and the pleura, on the abdominal side by the **transversal fascia** (fascia transversalis) and the peritoneum. A double layer of serosa extends between the thoracic surface and the heart and lungs. The abdominal surface is closely related to the liver and connected to it by ligaments. Its muscular part extends to the lumbar vertebral column dorsally.

There are **three openings in the diaphragm.** Just below the vertebral column, almost in the median plane it is penetrated by the **aorta** (aorta), the **azygos vein** (v. azygos) and the **thoracic duct** (ductus thoracicus). More ventrally and to the left is the **esophageal hiatus** (hiatus esophageus) through

Tab. 2-10. Muscles of the thoracic wall.

Name Innervation	Origin	Insertion	Action
Cranial dorsal serrate muscle Intercostal nerves	Spinocostotransverse fascia	Serrations of 2nd to 4th rib	Draws ribs forwards, extends the thorax
Caudal dorsal serrate muscle Intercostal nerves	Thoracolumbar fascia	From 9th to 12th rib	Draws ribs backwards, contracts the thorax
External intercostal muscle Intercostal nerves	Caudal border of the ribs	Cranial border of the proceeding rib	Draws ribs forwards, extends the thorax
Internal intercostal muscle Intercostal nerves	Cranial border of the ribs	Caudal border of the foregoing rib	Draws ribs backwards, contracts the thorax
Levator muscle of the ribs Dorsal branches of the thoracic nerves	Transverse and mamillary processes of the 1st until the thoracic vertebra before last	Cranial border of the proximal part of the proceeding rib	Draws ribs forwards, extends the thorax
Subcostal muscles Intercostal nerves	Thin bundle of muscle fibres between the proximal ends of the ribs		Supports the internal intercostal muscles
Retractor muscle of the ribs Costoabdominal nerve (Evans) Iliohypogastric nerve	Thoracolumbal fascia	Final rib	Draws ribs backwards
Straight thoracic muscle Intercostal nerves	1st rib	2nd–4th rib cartilage	Draws first three ribs forwards, extends the thorax
Transverse thoracic muscle Intercostal nerves	Sternal ligament	Costochondral articulations	Contracts the thorax

which the esophagus passes. The third opening, the **caval foramen** (foramen venae cavae) lies within the central tendon, to the right of the median plane, and forms a passage for the caudal vena cava. The diaphragm is innervated by the phrenic nerves of the ventral branches of the caudal cervical nerves.

The diaphragm consists of a **central tendon** (centrum tendineum) and a **muscular part,** which surrounds the tendinous center on all sides. The fibres of the muscular part arise on the inside of the thoracic wall and pass into the central part in a radial direction.

- The muscular part can be subdivided into:
  - Lumbar part (pars lumbalis),
  - Costal part (pars costalis) and
  - Sternal part (pars sternalis).

The **lumbar part** of the diaphragmatic musculature is formed by the **left and right diaphragmatic crura** (crus dexter, crus sinister) (Fig. 2-14). They originate from the ventral aspect of the third or fourth lumbar vertebra and extend in a cranioventrally direction. At the aortic hiatus they enclose the aorta, the azygos vein and the thoracic duct. The lumbar part is especially well-developed in carnivores.

The **right crus** (crus dexter) is larger than the left and fans out to divide into a lateral portion, which extends on the right side of the diaphragm to the central tendon and two ventral portions. The latter are strong muscular strands, which run cranioventrally and radiate deep into the central tendon. They form a slit through which the esophagus and the vagus nerves pass (hiatus oesophageus). In carnivores the division of the right crus is more complex and comprises dorsal, lateral, ventral and intermediate portions.

The **left crus** (crus sinister) is undivided in all domestic species, except in carnivores, where it consists of a lateral and an intermediate branch. The left crus extends from the dorsal border of the diaphragm on the left side to join the central tendon. The lumbar part is in direct contact to the peritoneum and the pleura on the dorsolateral border of the diaphragm just ventral to the psoas muscles. This area is called the **lumbocostal arch** (arcus lumbocostalis).

The **costal part** (pars costalis) originates as a series of muscle bundles from the inner surfaces of the last three or four ribs on both sides of the thorax and curves ventrally following the costochondral junctions to the eight rib and the xiphoid. It joins the central tendon in a radial pattern. The fibres of the **sternal part** (pars sternalis) arise from the xiphoid cartilage, extend dorsally to meet the central tendon (Fig. 2-14). The part of the central tendon, which projects the furthest cranially forms the vertex of the diaphragm and is also called cupula (cupula diaphragmatis).

The central tendon consists of two layers of tendon fibres, which arise from the muscular part of the diaphragm. Where-

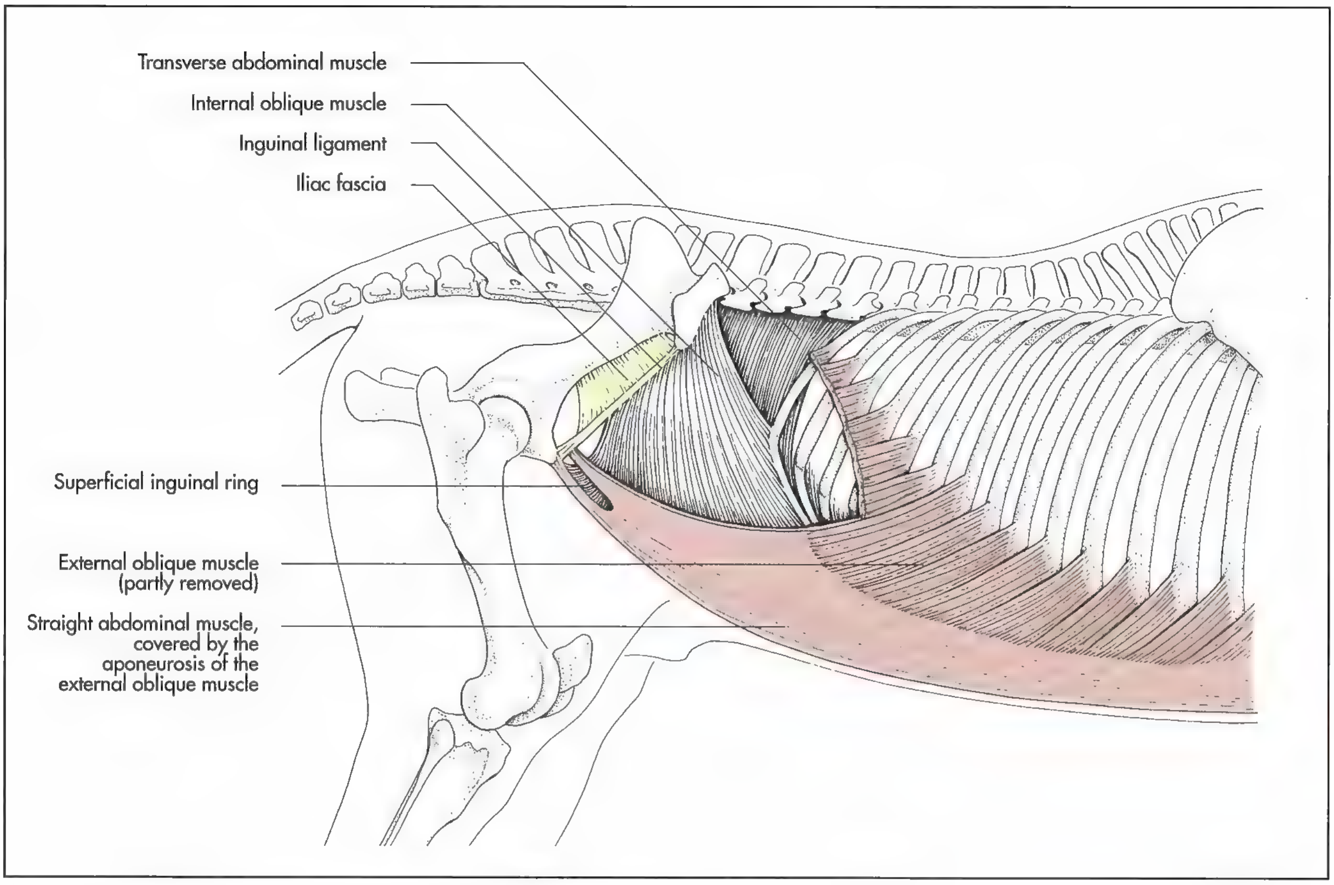

Fig. 2-15. Muscles of the thoracic wall of the horse (schematic, lateral aspect).

as the tendon fibres of the abdominal layer are arranged in a radial pattern, the fibres of the thoracic layer are orientated in a circular fashion, forming a mesh. Both layers are united by an intermediate layer of unorganised tendinous tissue. The central tendon is Y-shaped in carnivores due to the elongated extensions and resembles the sole of a horse's hoof in ungulates. It can be divided into a ventral body and two extensions, which run dorsally parallel to the crura. They reach the dorsal border of the diaphragm, where they separate the sternal and lumbar muscular portion. This division is incomplete in carnivores, in which the two portions stay united.

The apex of the cupula is formed by the caval foramen to which the caudal vena cava is firmly fused. Thus the position of the caval foramen is relatively constant. In the "neutral position" between full **inspiration** and full **expiration** the cupula extends into the thorax as far as the ventral part of the sixth rib and in the dog, the sixth intercostal space. This corresponds in the standing animal to the transverse plane through the olecranon. It is displaced one intercostal space caudoventrally during inspiration and one intercostal space craniodorsally during expiration. Consequently the apex of the cupula remains at the level of the seventh intercostal space in ruminants and the pig and between the seventh and eight intercostal space in carnivores and in the horse.

The diaphragm is orientated obliquely in the horse, but more vertical in the other domestic species. It drops off cranially towards the sternum and extends as flat arches laterally and dorsally to attach to the thoracic wall and the vertebral column. During **inspiration** the central tendon is tightened by the contraction of the surrounding muscles, which causes the diaphragm to become more conical. The lateral adominal wall is moved outward and the abdominal viscera are displaced caudally. Thus the thoracic cavity enlarges and the lungs expand passively.

During **expiration** the muscles of the diaphragm relax and the abdominal viscera move cranially, assisted by the abdominal muscles. The thoracic cavity is reduced and the lungs are compressed.

Muscles of the abdominal wall (mm. abdominis)

The muscles of the abdominal wall are extensive, relatively thin, muscular sheets, which constitute, together with their aponeuroses, the muscular and tendinous base of the abdominal wall. This group comprises several individual muscles, arranged in **three layers,** superimposed upon each other, with contrasting orientation of their fibres.

The muscles of this group arise from the cranial border of the pelvis, the lumbar region and the caudal part of the thorax and form the lateral and ventral wall of the body. These broad

fleshy sheets insert by means of an aponeurosis to tendinous structures, such as the linea alba in the midline and the **prepubic tendon** (tendo praepubicus) and the **inguinal ligament** (ligamentum inguinale) caudally (Fig. 2-16). They are innervated by the ventral branches of the thoracal and lumbar nerves.

The **linea alba** is a tendinous cord, which extends between the xiphoid cartilage and the cranial border of the pelvis, where it inserts to the prepubic tendon (Fig. 2-16). It is bordered by a strong muscle, the straight abdominal muscle, which pursues a sagittal course within the abdominal floor on both sides of the linea alba and is marked by tendinous intersections.

The inguinal ligament, which runs from the iliopubic eminence to the coxal tuberosity strengthens the iliac facia on either side of the prepubic tendon (Fig 2-16). There is a opening between the inguinal ligament, the iliac fascia and the cranial border of the pubis, which allows passage to the greater psoas and iliac muscles and, with the exception of carnivores, the sartorius muscle (lacuna musculorum). Ventromedially it forms a passage for the external iliac artery and vein, the deep femoral artery and vein, the saphenous nerve and lymphatic vessels (lacuna vasorum).

The linea alba is the ventromedian suture, where the bilateral parts of the lateral mesoderm unite during development (Fig. 2-16). It forms the **umbilical opening** (anulus umbilicalis) for the urachus and the umbilical vessels in the fetus, which becomes the scar-like umbilicus post partum. The linea alba reinforces the ventral abdominal wall together with the deep fascia of the trunk, with which it unites in the midline. In large animal the ventral part of the deep fascia of the trunk is interwoven by a mesh of elastic fibres. Due to the yellow colour of these fibres this part of the deep fascia is also called the **yellow abdominal tunic** (tunica flava abdominis).

The abdominal muscles fulfil a multitude of functions. They are an important part of the static-dynamic construction of the trunk, which supports the abdominal viscera. They also actively assist the end-phase of exspiration, especially during laboured respiration, by pushing the viscera cranially.

When the abdominal muscles contract against a fixed diaphragm, the animal is said to "strain". This results in an increase of the intraabdominal pressure, which reinforces the contractions of the visceral muscles, necessary during defecation, micturition and parturition.

These muscles play an important role during locomotion. In ruminants and the horse they assist in supporting the vertebral column during progression. Contracting bilaterally they assist in arching the back, which is of great importance in bounding gates. This is most obvious in carnivores, in which the abdominal muscles are far more fleshy than tendinous.

There are four abdominal muscles, which derive their names from their position and structure (Fig. 2-15, Table 2-11):

- External oblique abdominal muscle (m. obliquus externus abdominis),
- Internal oblique abdominal muscle (m. obliquus internus abdominis),
- Transverse abdominal muscle (m. transversus abdominis) and
- Straight abdominal muscle (m. rectus abdominis).

The **external oblique abdominal muscle** is the most superficial abdominal muscle and is only covered by the deep and superficial fasciae of the trunk and the abdominal part of the cutaneous muscle (Fig. 2-15 and 2-16). It has an extensive origin by a series of digitations from the lateral surfaces of the ribs caudal to the fourth or fifth rib. The more cranial digitations alternate with those of the ventral serrate muscles. Its origin curves caudodorsally until it reaches the end of the last rib, where it fuses with the thoracolumbar fascia. Based on position and course the external oblique abdominal muscle can be divided in a larger **thoracic portion,** which arises from the lateral surface of the thorax and a smaller **lumbar portion,** which originates from the last rib and the thoracolumbar fascia. In the horse it arises also from the coxal tuberosity.

The bulk of the muscle fibres fan out caudoventrally, but the dorsal bundles follow a more horizontal course. The fleshy part of the muscle is continued as a broad aponeurosis at the ventral quarter of the abdominal wall in carnivores and in the horse at the level of an imaginary line between the coxal tuberosity and the costochondral junction of the fifth rib. This extensive aponeurosis fuses ventrally with the aponeurosis of the internal oblique abdominal muscle, forming the external leaf of the **sheath of the straight abdominal muscle** (rectus sheath, vagina m. recti abdominis). It inserts to the linea alba and the prepubic ligament with the abdominal tendon and to the inguinal ligament with the pelvic tendon. In the inguinal region the aponeurosis divides into two main portions, which forms a slit-like opening, the **superficial inguinal ring** (anulus inguinalis superficialis) (Fig. 2-15 and 2-16).

The abdominal tendon forms the caudomedial wall (also called medial crus) of the superficial inguinal ring, the pelvic tendon the caudolateral wall (also called lateral crus). Corresponding to the course of the muscle fibres, the long axis of the superficial inguinal opening is directed from craniolateral to caudomedial. The superficial inguinal ring is the **external orifice of the inguinal canal** (canalis inguinalis seu spatium inguinale). Before or shortly after birth it allows the descent of the testis toward the scrotum

In the adult male the **vaginal process** (processus vaginalis), covered by the cremaster muscle and containing the spermatic cord, blood vessels and nerves passes through the inguinal canal. The medial crus detaches the **femoral lamina** (lamina femoralis), which passes onto the medial surface of the thigh, where it blends with the medial femoral fascia.

In carnivores, the abdominal tendon is fused with the deep fascia of the trunk on the outside and with the aponeurosis of the internal oblique abdominal muscle on the inside, forming the external leaf of the rectus sheath. The sheath itself blends with the transverse **tendinous intersections** (intersectiones tendineae) of the straight abdominal muscle. The lateral crus of the pelvic tendon unites with the medial crus in the caudal angle (angulus caudalis) of the superficial inguinal ring.

In the horse, the strong abdominal tendon is strengthened by the ventral part of the deep fascia of the trunk, the yellow abdominal tunic, and inserts along the linea alba and by means of the medial crus of the superficial inguinal ring to the prepubic tendon. The superficial inguinal ring is well-defined and about 10 to 15 cm long. It lies about 2 cm lateral to the linea alba and the same distance cranial to the prepubic ligament.The smaller

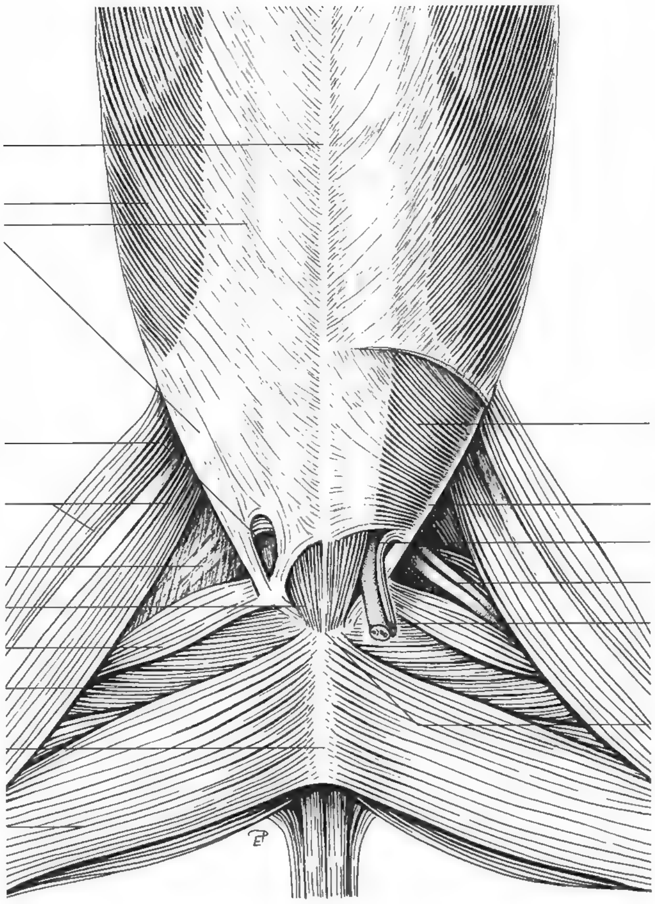

Fig. 2-16. Muscles of the abdominal wall and the medial side of the thigh (schematic, ventral aspect).

pelvic tendon forms the tendinous inguinal ligament (ligamentum inguinale), which extends from the coxal tuberosity to the iliopubic eminence and the prepubic tendon (Fig. 2-16).

The **internal oblique abdominal muscle** lies deep to the external oblique abdominal muscle. It originates from the tuber coxae, the proximal part of the inguinal ligament and, with the exception of the horse, from the transverse processes of the lumbar vertebrae and the thoracolumbar fascia (Fig. 2-15 and 2-16). It fans out in a cranioventral direction and its fibres are orientated in a right angle to the ones of the external oblique abdominal muscle. Its muscular part becomes a broad aponeurosis at the level of the lateral border of the straight abdominal muscle. It unites with the aponeurosis of the external oblique abdominal muscle to form the external leaf of the rectus sheath, which blends at the linea alba with that of the opposite side.

Proximally there is a separate portion, the **costocoxal crus** (crus costocoxale), which attaches to the last rib and the angle of the ribs. The caudal part of the internal oblique abdominal muscle forms the cranial wall of the deep inguinal ring (anulus inguinalis profundus), the caudal wall of which is formed by the inguinal ligament. The deep inguinal ring is the slit-like internal opening of the inguinal canal with its long axis orientated in a transverse direction.

In male animals the internal oblique abdominal muscle detaches a narrow muscular band caudally, the cremaster, which covers the vaginal process on its lateral surface and passes with the latter through the inguinal ring.

The **transverse abdominis** is the smallest of the four abdominal muscles and lies deep to the others (Fig. 2-15). It is a muscular sheet of parallel bundles of fibres, which originates cranially from the inside of the costal cartilages of the last 12 ribs in the horse and the 12th and 13th rib in the dog and caudally from the transverse processes of the lumbar vertebrae caudally. Its caudal border reaches the level of the coxal tuberosity. Its muscular part continues as an aponeurosis from the level of the lateral border of the rectus abdominis muscle. This aponeurosis constitutes the internal leaf of the rectus sheath. Since the transversus abdominis muscle does not extend beyond the level of the tuber coxae, the internal leaf of the rectus sheath is absent in the pelvic region. The aponeurosis does not extend as far as the inguinal canal. Well fed horses can deposit a large amount of fat between the fascia transversalis and the transverse abdominal muscle (panniculus adiposus internus). In carnivores the aponeurosis extends a detachment to the external sheath of the straight abdominal muscle caudal to the umbilicus.

Tab. 2-11. Muscles of the abdominal wall.

Name Innervation	Origin	Insertion	Action
External oblique muscle Ventral branch of the thoracic and lumbar nerves	Digitations from the lateral surface of the ribs 8 to 10 and the thoracolumbar fascia	Linea alba and inguinal lig.	Abdominal press and expiration, compression of the abdominal viscera
Internal oblique muscle Ventral branch of the thoracic and lumbar nerves	Coxal tuberosity, transverse processes of the lumbar vertebrae, thoracolumbar fascia	Linea alba and final rib costal arch	Abdominal press and expiration, compression of the abdominal viscera
Transverse abdominal muscle Ventral branch of the thoracic and lumbar nerves	Transverse processes of the lumbar vertebrae, rib cartilage	Linea alba	Abdominal press and expiration, compression of the abdominal viscera
Straight abdominal muscle Ventral branch of the thoracic and lumbar nerves	Sternum, sternal rib cartilage from the 4th rib	Prepubic tendon and pecten of pubic bone	Abdominal press and expiration, compression of the abdominal viscera

The **straight abdominal muscle** is confined to the ventral aspect of the abdominal wall and does not form an aponeurosis unlike the other abdominal muscles (Fig. 2-15 and 2-16). The entire muscle lies within a sheath, the rectus sheath, which is formed by the aponeuroses of the other abdominal muscles in a species specific way (vagina musculi recti abdominis). The straight abdominal muscle arises from the costal cartilages of the true ribs and the adjacent parts of the sternum and inserts in to the prepubic tendon. The fibres of the muscles are directed longitudinally on both sides of the linea alba. Transverse bands of fibrous tissue extend across the muscle, called tendinous intersections. In the horse the tendon of insertion of the straight abdominal muscle detaches to form the accessory ligament of the femoral head, which runs to the coxofemoral joint, where it inserts together with the ligament of the head of the femur, to the head of the femur.

Rectus sheath (vagina m. recti abdominis)

The straight abdominal muscle is completely surrounded by tendinous tissue, which is composed of the aponeuroses of the three other abdominal muscles and the deep fascia of the trunk (Fig. 2-17). If species specific variations are neglected the rectus sheath shows the following architecture: The aponeuroses of the two oblique abdominal muscles form the **external leaf of the sheath** (lamina externa), which covers the ventral aspect of the rectus abdominis. Dorsally the rectus abdominis is covered by the **internal leaf of the sheath** (lamina interna), which is formed by the aponeurosis of the transversus abdominis. Both leaves unite in the linea alba. The described anatomical plan is found in ruminants and horses and is limited to the region of the umbilicus in pigs and carnivores.

In the pre-umbilical region of carnivores the aponeurosis of the internal oblique abdominal muscle divides to form the tendinuous sheet of the internal leaf of the rectus sheath. In the region caudal to the umbilicus the aponeurosis of the transverse abdominal passes gradually over to the lateral side, where it unites with the aponeuroses of the oblique muscles and the fascia transversalis to form the external leaf of the rectus sheath. Thus the straight abdominal muscle lacks an internal aponeurotic covering at its pelvic end, being covered here by the transverse fascia and the peritoneum only.

Inguinal canal (canalis inguinalis)

The inguinal canal is a connective tissue-filled cleft between the abdominal muscles and their aponeuroses in both sexes. It serves as a passageway for the vaginal process and for the descent of the testis before or shortly after birth in male animals.

The external opening of the inguinal canal is called **superficial inguinal ring** (angulus inguinalis superficialis). In the horse it is situated 4 to 5 cm lateral to the linea alba and 2 to 3 cm cranial to the cranial border of the pelvis (Fig. 2-15 and 2-16).

In a middle-sized horse the superficial inguinal ring is a well-defined slit-like opening, about 10 to 12 cm long, with its long axis directed from craniolateral to caudomedial. Its ventromedial wall is formed by the medial crus of the abdominal tendon of the external oblique abdominal muscle, its dorsolateral wall by the lateral crus of the pelvic tendon of the latter muscle. The ventromedial wall of the superficial inguinal ring is palpable through the skin between the abdominal wall and the thigh. The dorsolateral wall cannot be palpated since it is covered by the femoral lamina.

The internal opening of the inguinal canal, the **deep inguinal ring** (anulus inguinalis profundus) is orientated transversally to the long axis of the body (Fig. 2-16). The deep inguinal ring is formed by the caudal border of the internal oblique abdominal muscle and the lateral border of the straight abdominal muscle craniomedially and the inguinal ligament caudolaterally. The inguinal ligament (ligamentum inguinale) is the thickened caudal end of the pelvic tendon

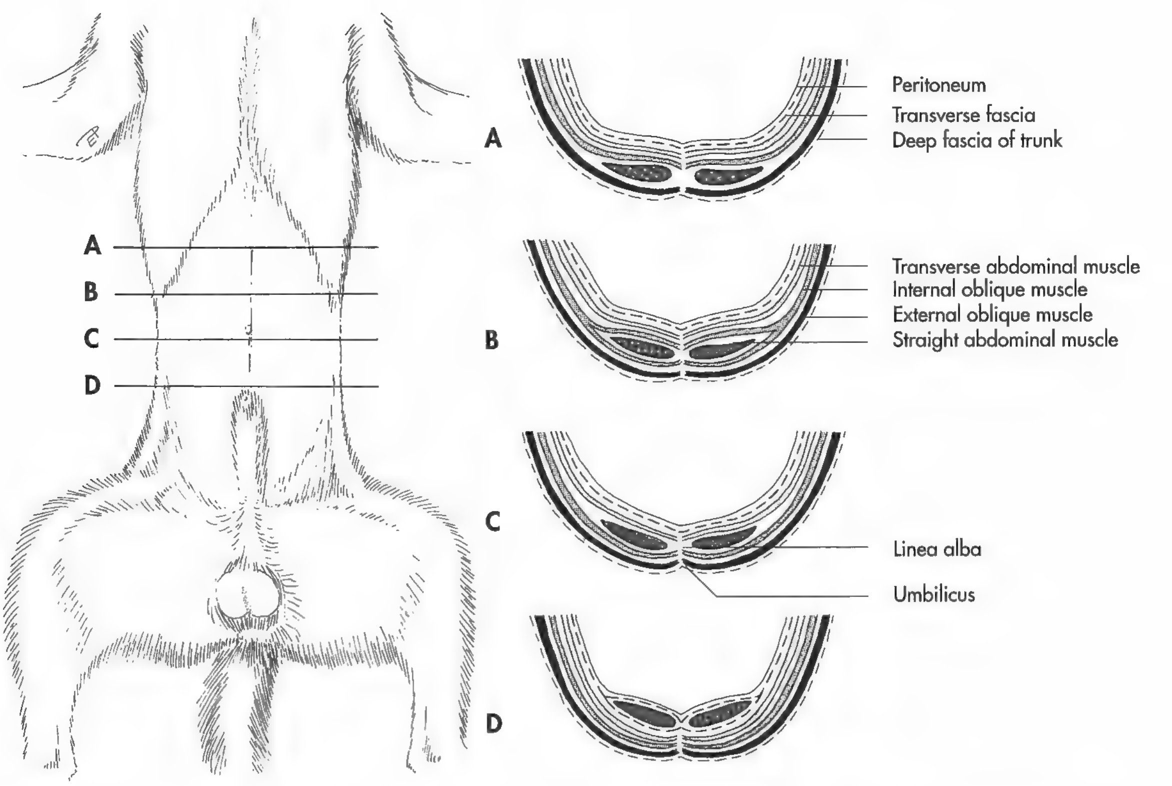

Fig. 2-17. Rectus sheath of the dog with cross sections through the ventral abdominal wall at four levels (schematic) (Budras, 1996).

of the external oblique abdominal muscle and is closely related to the transverse fascia. It extends between the iliopubic eminence and the prepubic tendon.

In the adult male the inguinal canal contains the vaginal process, which includes the spermatic cord and the cremaster muscle (m. cremaster) on the lateral aspect. The spermatic cord can be palpated through the skin and the wall of the vaginal process, in the horse.

The caudomedial angle of the superficial inguinal ring leaves room for the passage of blood and lymphatic vessels (a. et v. pudenda externa, vasa efferentia of the superficial inguinal lymph nodes) and the genitofemoral nerve (n. genitofemoralis) through the inguinal canal. In the females of the domestic mammals the inguinal canal is very narrow and allows passage to the same vessels and nerves as in males. Only the bitch possesses a vaginal process, which contains the round ligament of the uterus.

The inguinal region is of clinical relevance in connection with castration, inguinal hernias and cryptorchidism.

Muscles of the tail (mm. caudae)

The tail of the domestic mammals has a variety of functions for which its versatile attachment to the trunk is very important. It can influence movements of the whole body considerably. The tail expresses a wide range of emotions and acts as a means of communication especially in carnivores. The muscles of the tail are arranged in a circular order around the caudal vertebrae.

They are direct continuations of muscles, which arise from the vertebral column or the pelvis.

- **Levators of the tail:**
  - Medial dorsal sacrococcygeal muscle (m. sacrococcygeus dorsalis medialis),
  - Lateral dorsal sacrococcygeal muscle (m. sacrococcygeus dorsalis lateralis).
- **Depressors of the tail:**
  - Medial ventral sacrococcygeal muscle (m. sacrococcygeus ventralis medialis),
  - Lateral ventral sacrococcygeal muscle (m. sacrococcygeus ventralis lateralis).
- **Lateral flexors of the tail:**
  - Intertransverse muscles of the tail (mm. intertransversarii caudae).
- **Muscles of the pelvis and tail:**
  - Coccygeal muscle (m. coccygeus),
  - Iliocaudal muscle (m. iliocaudalis) and
  - Pubocaudal muscle (m. pubocaudalis).

The **muscles of the tail,** which arise from the vertebral column lie on the lateral, ventral and dorsal side and cover the individual vertebrae and the intervertebral discs (Fig. 2-18 and Table 2-19). The levators of the tail are situated on the

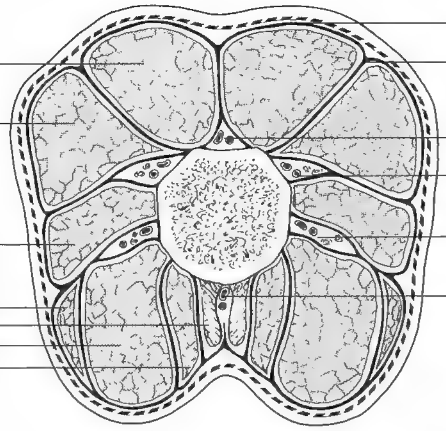

Fig. 2-18. Muscles of the tail of the dog, cross section (schematic).

dorsal aspect of the caudal vertebrae and extend from the sacrum (in carnivores from the last lumbar vertebra) to the middle or last caudal vertebrae.

The **medial dorsal sacrococcygeal muscle** is also called the short levator of the tail and is composed of short, individual segments, which extend between the spinal and mammary processes (Fig. 2-18). In carnivores it lies to both sides of the median plane on the dorsal side of the sixth or seventh lumbar vertebra to the last caudal vertebra. It has short deep muscle portions, which originate from the spinous process, bridge one intervertebral space and insert on the mammillary process of the vertebra caudal to it and long superficial portions, which span four or five caudal vertebrae. The muscle segments become smaller towards the tip of the tail.

The **lateral dorsal sacrococcygeal muscle,** also called the long levator of the tail is considered to be the direct continuation of the longissimus muscle of the back on the tail (Fig. 2-18). In the dog it has a muscular origin from the aponeurosis of the longissimus and a tendinuous origin from the mammillary processes of the second to seventh lumbar vertebra, the articular processes of the sacrum and the rudiments of the mammillary processes of the first eigth caudal vertebrae. It is composed of individual segments, which extend from the second sacral to the 14th caudal vertebra. These muscular segments continue as 16 thin, delicate tendons, embedded in the deep fascia of the tail, which taper towards the tip of the tail. In ruminants and horses there are additional tendons originating from the lateral part of the sacrum.

The **medial ventral sacrococcygeal muscle,** or short depressor of the tail, covers the ventral side of the vertebral column, starting with the last sacral vertebra throughout the length of the tail (Fig. 2-18). It is a cord-like muscle, which forms, with the muscle of the opposite side, a deep furrow for the coccygeal vessels (a. et v. coccygea mediana). Its tendons of insertion unite with the tendon of the long depressor of the tail.

The **lateral ventral sacrococcygeal muscle,** or long depressor of the tail, consists of numerous individual parts, which originate lateral and ventral to the short depressor of the tail from the last lumbar vertebra, the sacrum and on the ventral aspect and the basis of the transverse processes of the first 11 caudal vertebrae in carnivores (Fig. 2-18). The single segments insert on the ventrolateral tubercles on the cranial end of the sixth caudal vertebra. In ungulates it is a strong muscular cord, which originates from the second, third or last sacral vertebra and the transverse process of the first caudal vertebra.

The **intertransverse muscles of the tail** flex the tail laterally. They are situated on the lateral side of the caudal vertebrae between the long levator and the long depressor of the tail (Fig. 2-18). They occupy the spaces between the transverse processes of the caudal vertebrae and are especially well-developed in ruminants and the horse. In carnivores the intertransversarii caudae muscles exhibits ventral and dorsal muscle bundles.

The **dorsal parts** originate from the dorsal sacroliliac ligament (ligamentum sacroiliacum dorsale) and from the caudal part of the sacrum. The single portions form a large round muscle belly, which insert on the transverse process of the fifth caudal vertebra. It receives supplementary fibres from the transverse processes of the first few caudal vertebrae.

The **ventral intertransverse muscle of the tail** extends from the third to the last caudal vertebra.

The **muscles of the pelvis and tail** are individual muscles, which extends from the pelvis to the transverse or hemeal processes of the first caudal vertebrae. They insert between the levators and depressors of the tail.

The **iliocaudal muscle** and the **pubocaudal muscle** are only present in carnivores and are part of the levator muscles of the anus. The iliocaudal muscle constitutes the ilial portion of the levator muscle of the anus, originating from the medial aspect of the ilial shaft. The pubocaudal muscle constitutes the pubic portion, arising from the floor of the pelvis along the pelvic symphysis. The obturator nerve (n. obturatorius) passes between the two parts. The fibres of both parts radiate

Tab. 2-12. Muscles of the tail.

Name Innervation	Origin	Insertion	Action
Lateral dorsal sacrococcygeal muscle Sacral and caudal nerves	Sacrum	Middle and last caudal vertebrae	Levator of the tail
Medial dorsal sacrococcygeal muscle Sacral and caudal nerves	Sacrum	Middle and last caudal vertebrae	Levator of the tail
Lateral ventral sacrococcygeal muscle Sacral and caudal nerves	Ventral on the sacrum	Middle and last caudal vertebrae	Depressor of the tail
Medial ventral sacrococcygeal muscle Sacral and caudal nerves	Ventral on the sacrum	Middle and last caudal vertebrae	Depressor of the tail
Intertransverse muscles of the tail Caudal nerves	Transverse processes of the caudal vertebrae	Middle and last caudal vertebrae	Draws tail sideways
Coccygeal muscle Sacral and caudal nerves	Ischiatic spine and sacrotuberal ligament	Transverse processes of the first caudal vertebrae	Draws tail sideways
Iliocaudal muscle (only carnivores) Sacral and caudal nerves	Medial on the shaft of the ilium	Haemal processes of the first caudal vertebrae	Depressor of the tail
Pubocaudal muscle (only carnivores) Sacral and caudal nerves	Pelvic symphysis	Haemal processes of the first caudal vertebrae	Depressor of the tail

into the fascia of the tail or end on the haemal processes of the first to third (cat) or fourth to seven (dog) caudal vertebra.

The **coccygeal muscle** takes its origin from the inside of the broad sacrotuberous ligament in ruminants, pigs and the horse. In carnivores it originates cranial to the internal obturator muscle from the ischial spine and inserts on the transverse processes of the first caudal vertebrae between the portions of the intertransverse muscles of the tail. Acting bilaterally it presses the tail against the anus and genitalia and draws the tail between the hindlimbs. Acting unilaterally it flexes the tail laterally.

3 Forelimb or thoracic limb (membra thoracica)

H.-G. Liebich, H. E. König and J. Maierl

Skeleton of the thoracic limb (ossa membri thoracici)

Pectoral girdle (cingulum membri thoracici)

The pectoral or shoulder girdle comprises the **coracoid,** the **collar bone** (clavicle, clavicula) and the **shoulderblade** (scapula) and joins the forelimb to the trunk.

In domestic mammals, the coracoid is reduced to a cylindrical process (coracoid process, processus coracoideus) fused to the medial side of the scapula. The clavicle is either absent or a small rudiment embedded in the brachiocephalic muscle, in contrast to the well developed functional bone of man. In the cat it forms a flat, slightly bent bone, 2–5 cm in length whereas in the dog it is only 1cm in length with no connection to the skeleton. These rudimentary bones are visible on radiographs. In ungulates it is further reduced to a fibrous intersection in the brachiocephalic muscle.

Shoulderblade (scapula)

The scapula is triangular in outline and lies flat against the cranial part of the lateral thoracic wall in a cranioventral direction. It is linked to the trunk by muscles (synsarcosis) without forming a true articulation. The **dorsal border** (margo dorsalis) points towards the vertebral column and extends into the crescent shaped scapular cartilage (cartilago scapulae) which enlarges the area of attachment for the muscles of the scapula and acts as a shock absorber. This cartilage becomes increasingly calcified and thus more brittle with age. In the horse the scapular cartilage extends over the caudal angle and reaches the level of the withers, in carnivores it is only a small band. Table 3-1 shows the times when the separate ossification centers appear and the times of their fusion.

Fig. 3-1. Right and left clavicle of a cat.

The **lateral surface** (facies lateralis) of the scapula carries prominent bony structures, whereas the **medial or costal surface** is hollowed by a shallow fossa (fossa subscapularis) for muscular attachment. The lateral surface is divided by the prominent **spine of the scapula** (spina scapulae) into the smaller cranial **supraspinous fossa** (fossa supraspinata) and the larger **infraspinous fossa** (fossa infraspinata) caudally (Fig. 3-4, 6 and 7). The muscle bellies of the like-named muscles are found within these fossae. The scapular spine extends from the dorsal border to the ventral angle, increasing in height (distance from the scapula) dorsoventrally.

The spine ends with a well defined prominence (acromion) close to the ventral angle, in carnivores and ruminants, but in the horse and pig it subsides distally. This prominence is extended to form a distinct process in the dog (processus hamatus) and cat (proccessus suprahamatus). The **tuberosity of the spine of the scapula** (tuber spinae scapulae) is present dorsal to its middle in all domestic mammals with the exception of the carnivores.

The **costal surface of the scapula** (facies costalis seu medialis) is hollowed by the shallow **subscapular fossa** (fossa subscapularis), which is occupied by the origin of the subscapularis muscle (Fig. 3-6 and 7). On the proximal border a roughened area (facies serrata), where the ventral serrate muscle attaches extends dorsally. This area is surrounded by a bony rim. The outline of the scapula can be defined by different features, which are described below in a counterclockwise direction:

- Cranial angle (angulus cranialis),
- Cranial border (margo cranialis),
- Ventral angle (angulus ventralis),
- Caudal border (margo caudalis),
- Caudal angle (angulus caudalis) and
- Dorsal border (margo dorsalis).

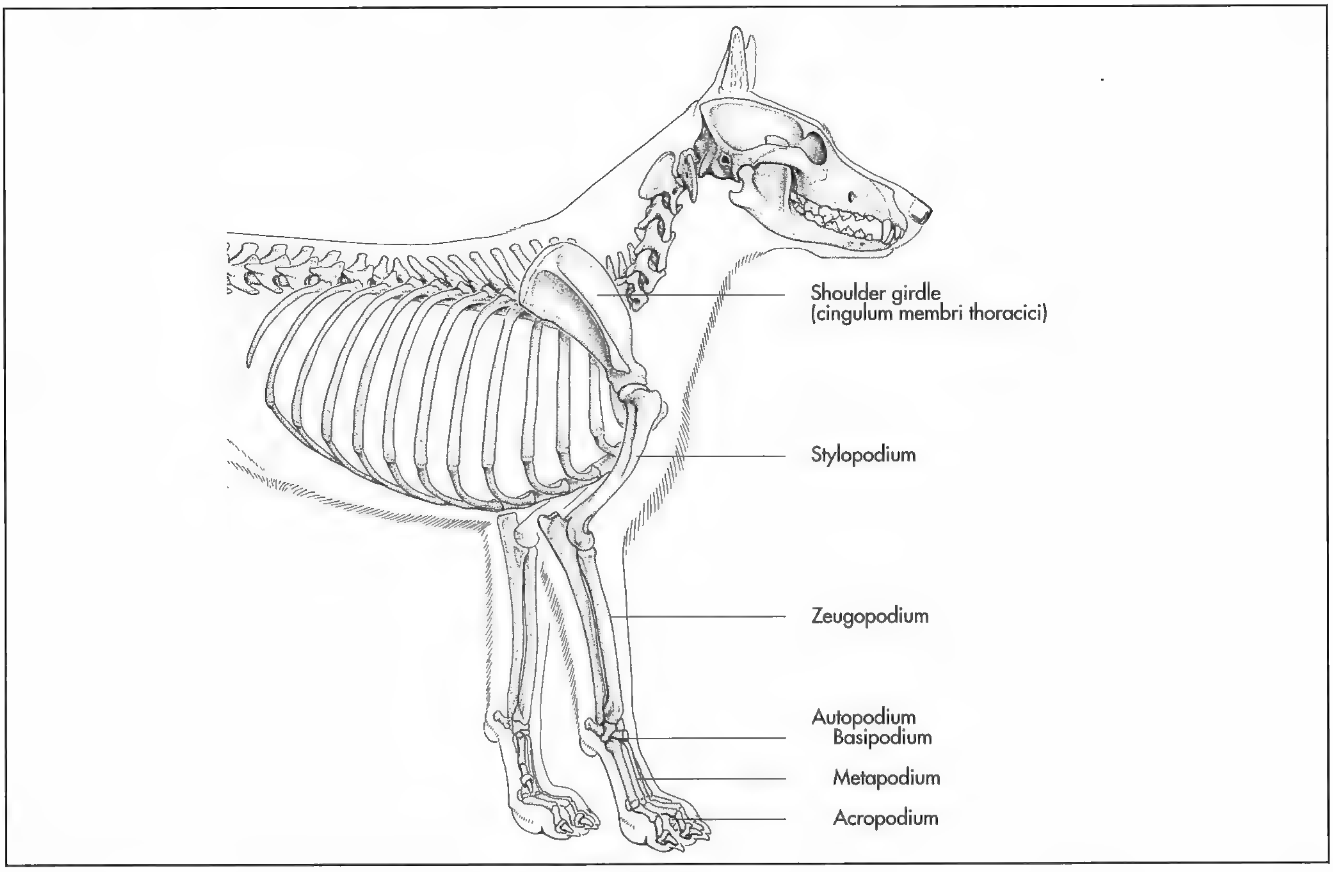

Fig. 3-2. Skeleton of the thoracic limb of the dog: Parts (schematic).

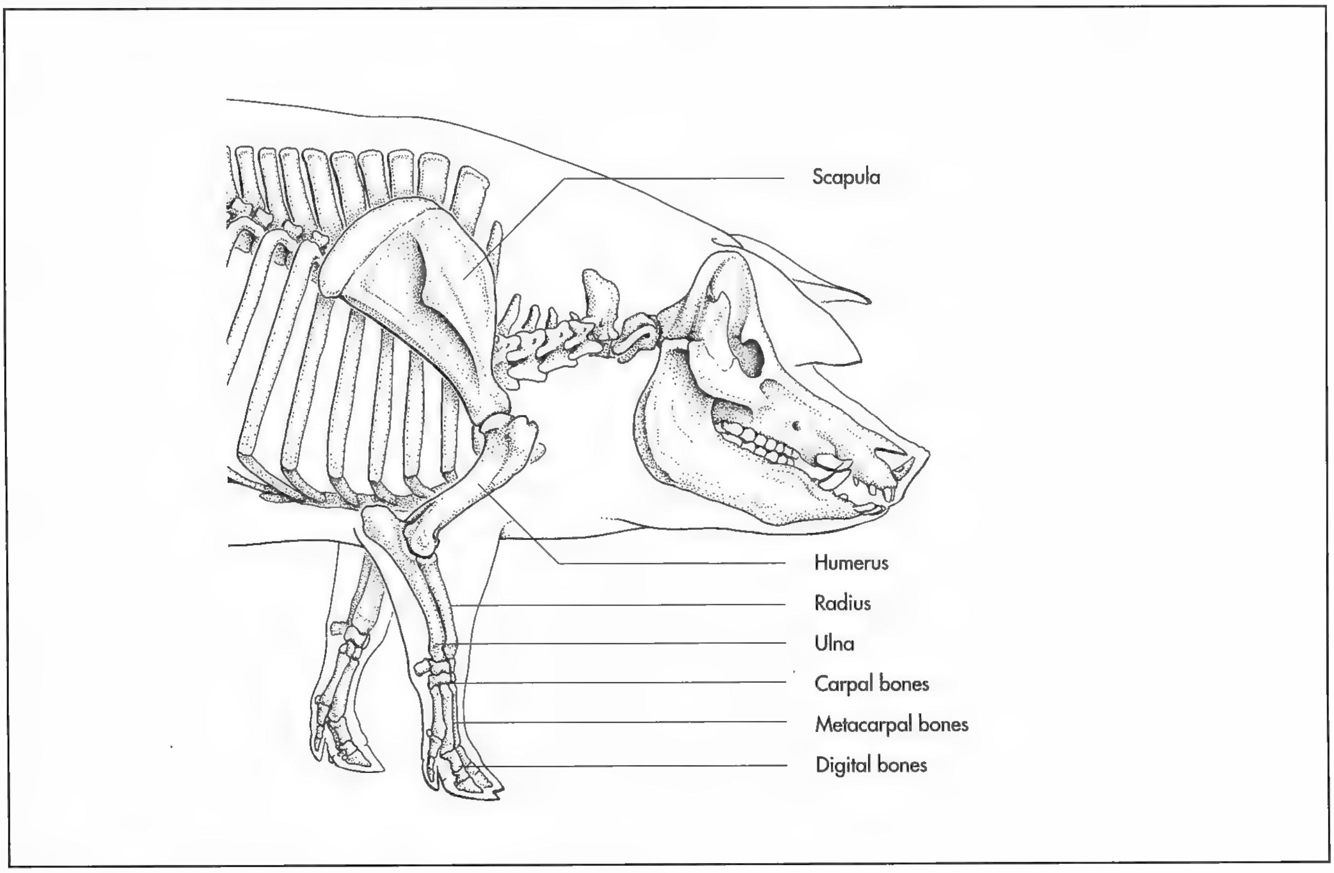

Fig. 3-3. Skeleton of the thoracic limb of the pig: Bones (schematic).

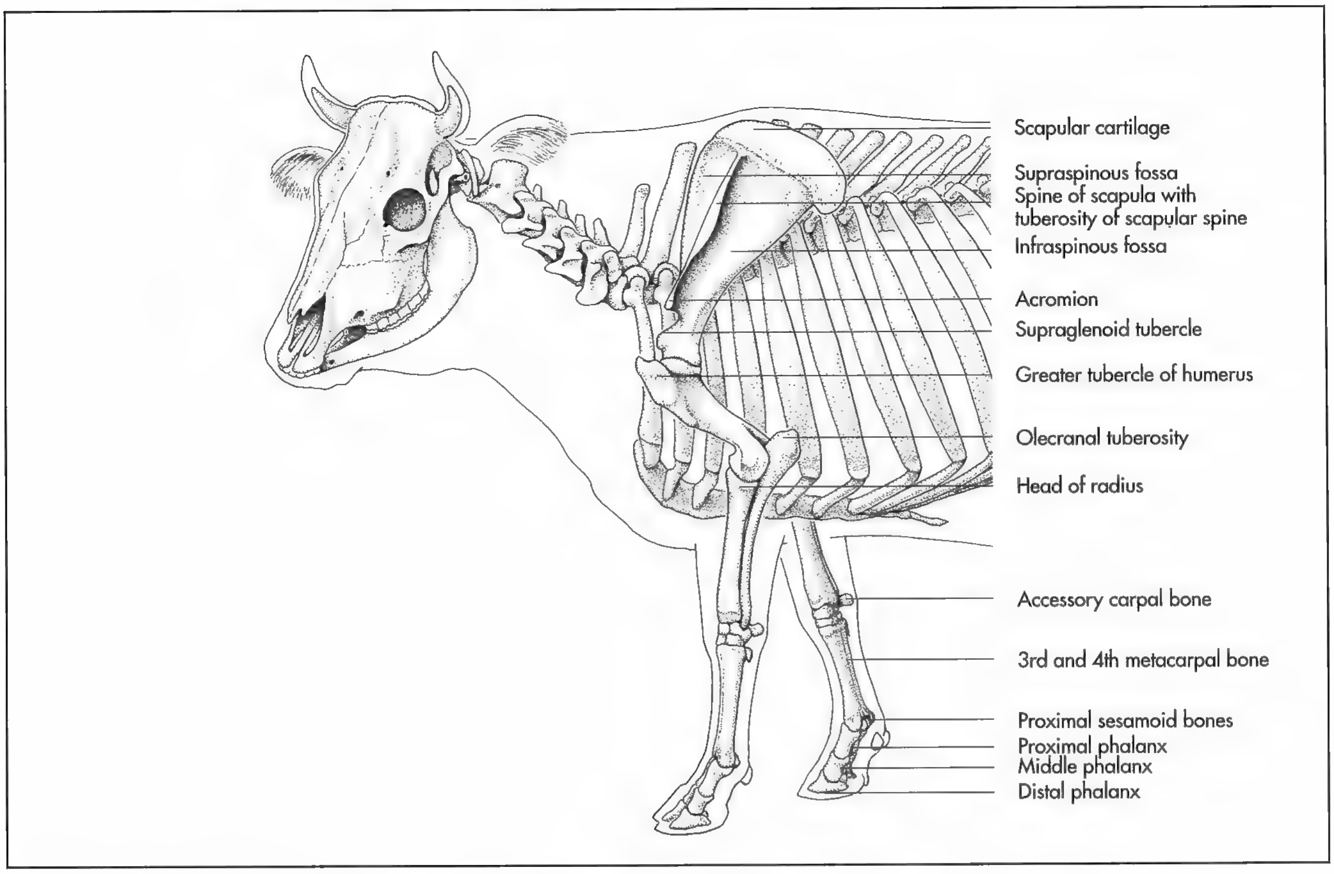

Fig. 3-4. Skeleton of the thoracic limb of the ox: Osseous structures (schematic).

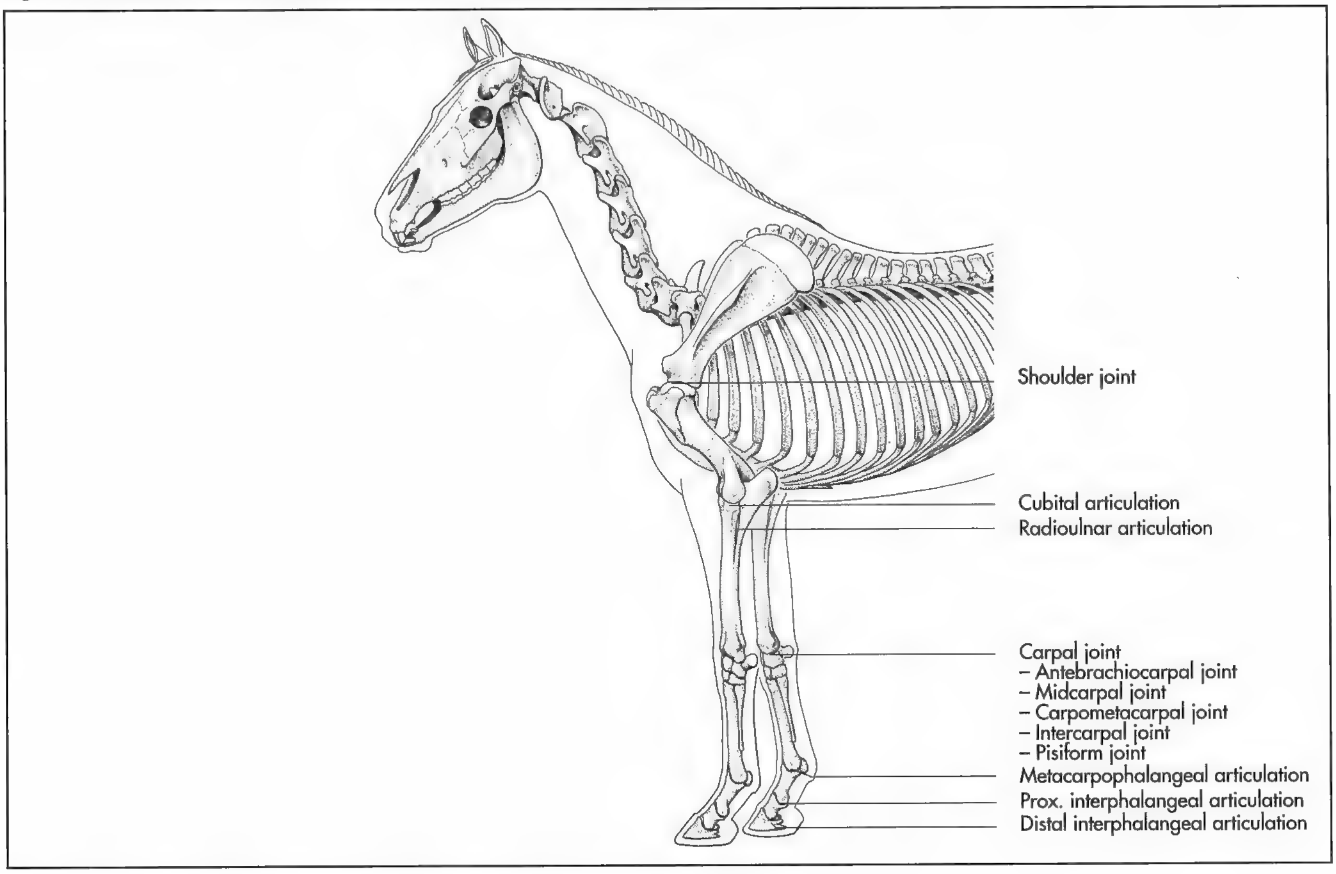

Fig. 3-5. Skeleton of the thoracic limb of the horse: Joints (schematic).

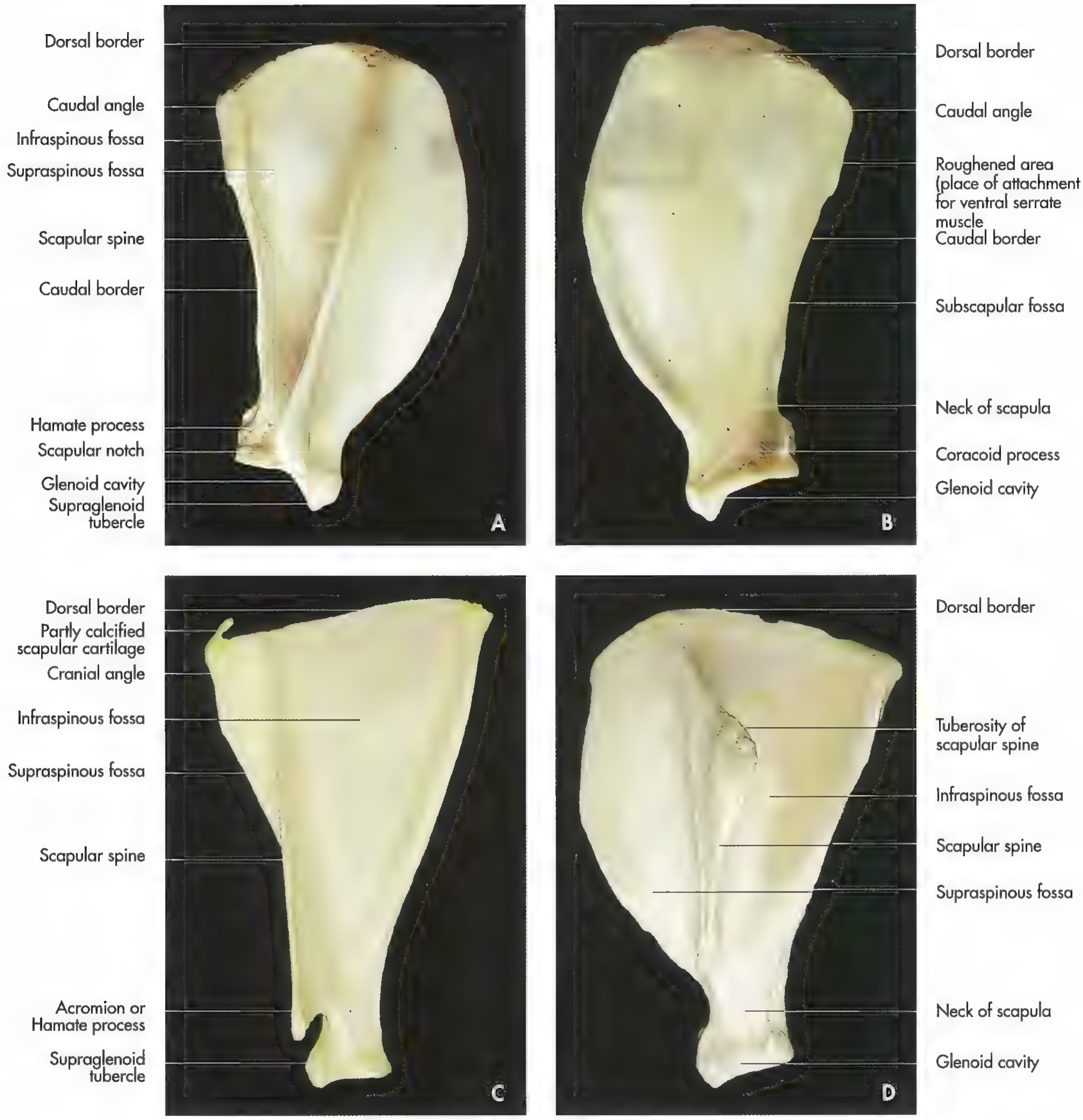

Fig. 3-6. Comparison of the scapula of a dog (**A** lateral and **B** medial aspects), of a small ruminant (**C** lateral aspect) and a pig (**D** lateral aspect).

Tab. 3-1. Appearance and fusion of the ossification centres on the scapula (Ghetie, 1971).

Species	Primary ossification centre Appearance	Coracoid process Appearance/Fusion	Tuberosity of the spine Appearance/Fusion
Horse	2nd month of pregnancy	7th month of pregnancy/10th–12th month of pregnancy	after birth / 4th year
Ox	2nd month of pregnancy	7th month of pregnancy/ 7th–10th month of pregnancy	after birth / 4th year
Carnivores	4th week of pregnancy	2nd month of pregnancy/ 5th–8th month of pregnancy	

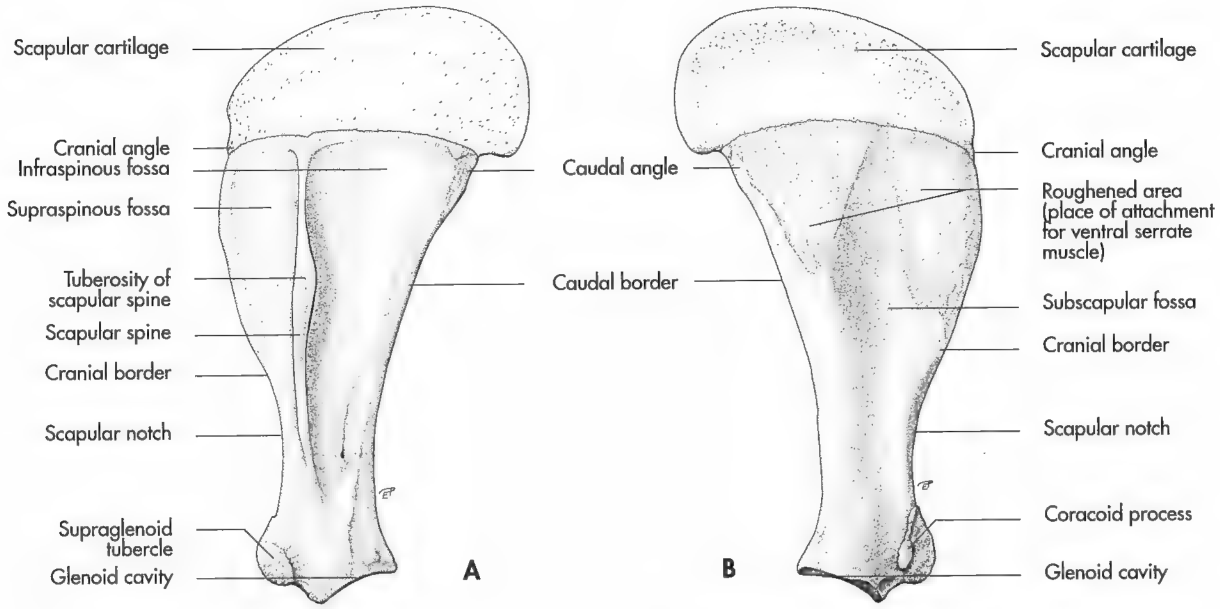

Fig. 3-7. Left scapula of the horse (schematic, lateral (**A**) and medial (**B**) aspect).

The **cranial angle** joins the thin and slightly concave **cranial border** (margo cranialis) at a right angle. The cranial border forms the **scapular notch** (incisura scapulae) at the level of the **neck of the scapula** (collum scapulae), where the suprascapular nerve lies. The **ventral angle** (angulus ventralis) carries the shallow **glenoid cavity** (cavitas glenoidalis) for the articulation of the scapula with the humerus (glenohumeral joint, shoulder joint, articulatio humeri). Cranial to the glenoid cavity is a large prominence, the **supraglenoid tubercle** (tuberculum supraglenoidale), which gives origin to the biceps muscle of the forearm. The **coracoid process** (processus coracoideus) projects from the medial side of the supraglenoid tubercle. The thick **caudal border** is marked by several ridges for the attachment of the triceps muscle of the forearm. The **caudal angle** is also thickened and palpable through the skin.

Skeleton of the arm (brachium)

The skeleton of the proximal part (stylopodium) of the free appendage of the forelimb is formed by a single bone, the **humerus** (Fig. 3-2). The appearance and fusion of the separate ossification centers of the humerus are summarised for the different species in Tab. 3-2. The humerus has a central function in the movement of the thoracic limb. Its surface is characteristically modelled by the attachment of strong muscles and their tendons, which led to the development of prominent bony protuberances and grooves. (Fig. 3-3 and 4). In spite of species specific modifications the humerus can be divided into three basic segments (Fig. 3-8 and 9):

- Proximal extremity carrying the head and the tubercles,
- Shaft of humerus (corpus humeri) and
- Distal extremity bearing the humeral condyle.

Tab. 3-2. Appearance and fusion of the ossification centres on the epiphysis of the humerus (Ghetie, 1971).

Species	Appearance	Fusion distal	Fusion proximal
Horse	middle of 2nd month pregnancy	15th – 18th month	3½ years
Ox	middle of 2nd month pregnancy	15th – 18th month	3½ years
Carnivores	4th week of pregnancy	6th – 8th month	1 – 1½ years

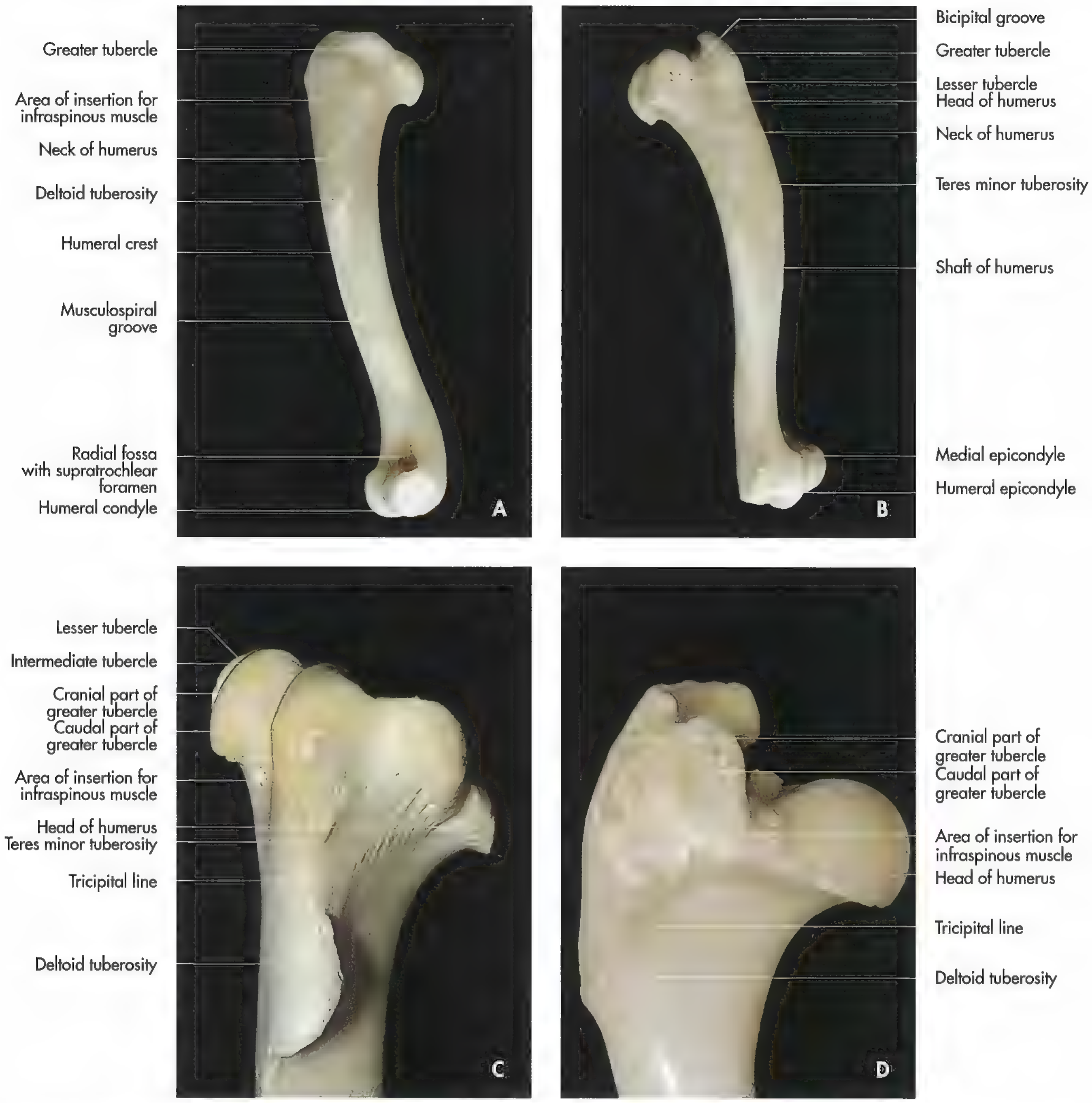

Fig. 3-8. Left humerus of a dog (**A** lateral, **B** medial aspect) and proximal extremity of the left humerus of a horse (**C** lateral aspect) and a pig (**D** lateral aspect).

The caudal part of the **proximal extremity** (extremitas seu epiphysis proximalis) carries the **head of the humerus,** which forms a circular convex articular surface for the articulation with the considerably smaller glenoid cavity of the scapula. (Fig. 3-8, 9 and 10).

The **humeral head** (caput humeri) is separated from the shaft of the humerus by a well defined **neck** (collum humeri), which is most pronounced in the dog and cat. The **greater tubercle** (tuberculum majus) is placed on the craniolateral side of the humeral head and the **lesser tubercle** (tuberculum minus) craniomedially. They are separated by the **bicipital groove** (sulcus intertubercularis), through which the tendon of origin of the biceps muscle of the forearm runs. The bicipital groove is subdivided by a flat protuberance in ruminants and a prominent ridge (intermediate tubercle, tuberculum intermedium) in the horse.

The greater tubercle consists of a cranial and a caudal part in all species, except the cat. In ruminants and in the horse the lesser tubercle is also divided into two parts.

The greater and lesser tubercle gives insertion to the muscles of the shoulder blade (infraspinous and supraspinous muscle), which brace and support the shoulder joint (Fig. 3-5 and 10).

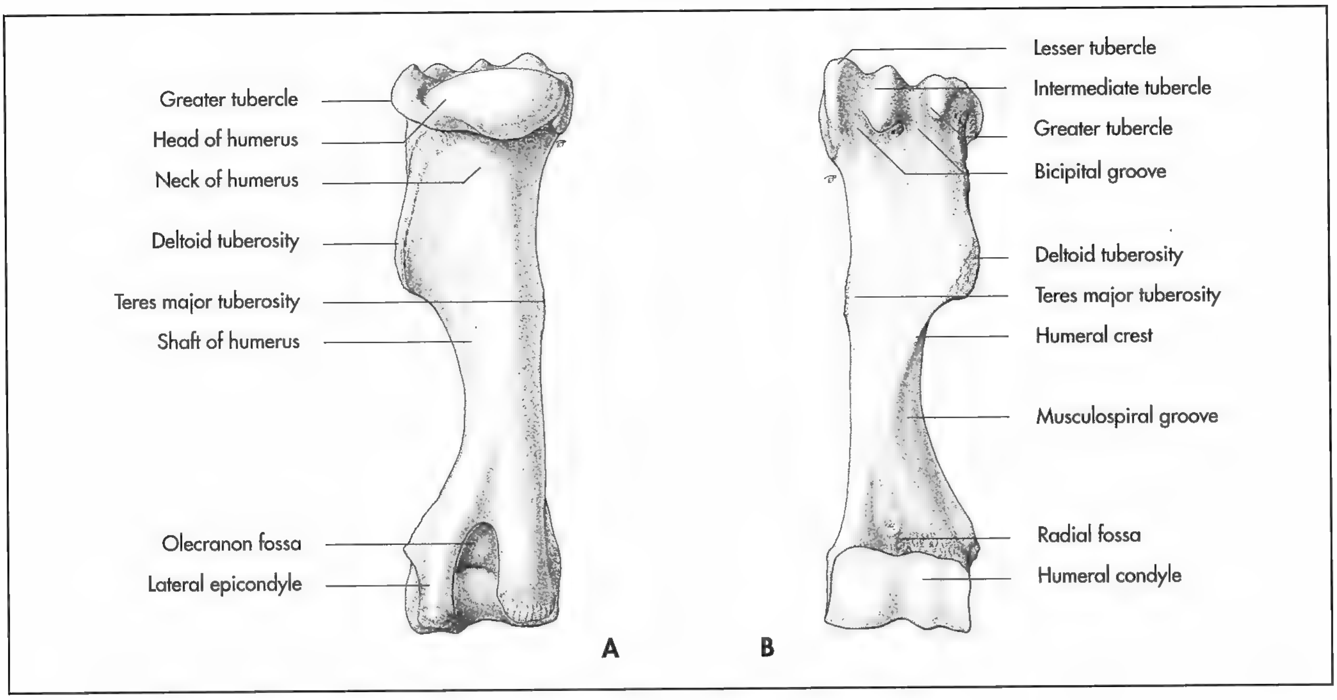

Fig. 3-9. Left humerus of the horse (schematic, caudal (**A**) and cranial (**B**) aspect).

The **humeral shaft** or **body** is the **middle part** (diaphysis) of the humerus. The broad musculospiral groove (sulcus musculi brachialis), which spirals over the lateral aspect of the shaft imparts a characteristic appearance to the humeral body around which the brachial muscle and radial nerve pass.

The **deltoid tuberosity** (tuberositas deltoidea) is located on the lateral aspect of the humeral shaft, just proximal to its middle and extends distally as the **humeral crest** (crista humeri). It forms the insertion of the deltoid muscle. A rough line (linea musculi tricipitis), which gives attachment to the triceps muscle, curves from the deltoid tuberosity proximally to the insertion of the **teres minor muscle** (teres minor tuberosity, tuberositas teres minor) (Fig. 3-8) distally. In ruminants and in the horse, the **teres major tuberosity** (tuberositas teres major) is located on the medial surface of the humeral shaft, just proximal to its middle; in carnivores the tuberosity is replaced by the **crest of the greater tubercle** (crista tuberculi minoris).

The **distal extremity** (extremitas seu epiphysis distalis) bears the **humeral condyle** (condylus humeri), which is set at a right angle to the axis of the humeral shaft. The condyle articulates with the bones of the forearm; the radius and ulna, forming the **elbow joint** (articulatio cubiti) (Fig. 3-5 and 13). In the dog and the cat the condyle is divided into a more extensive medial part (trochlea humeri), which articulates with the ulna, and a **capitulum** (capitulum humeri) laterally for the articulation with the radius. The articular surface is further divided by sagittal ridges in ungulates.

To both sides of the condyle are thick **protuberances,** the **epicondyles,** which give origin to the musculature of the distal

Abb. Fig. 3-10. Radiograph of the shoulder joint of a dog (mediolateral (**A**) and lateromedial (**B**) projection).

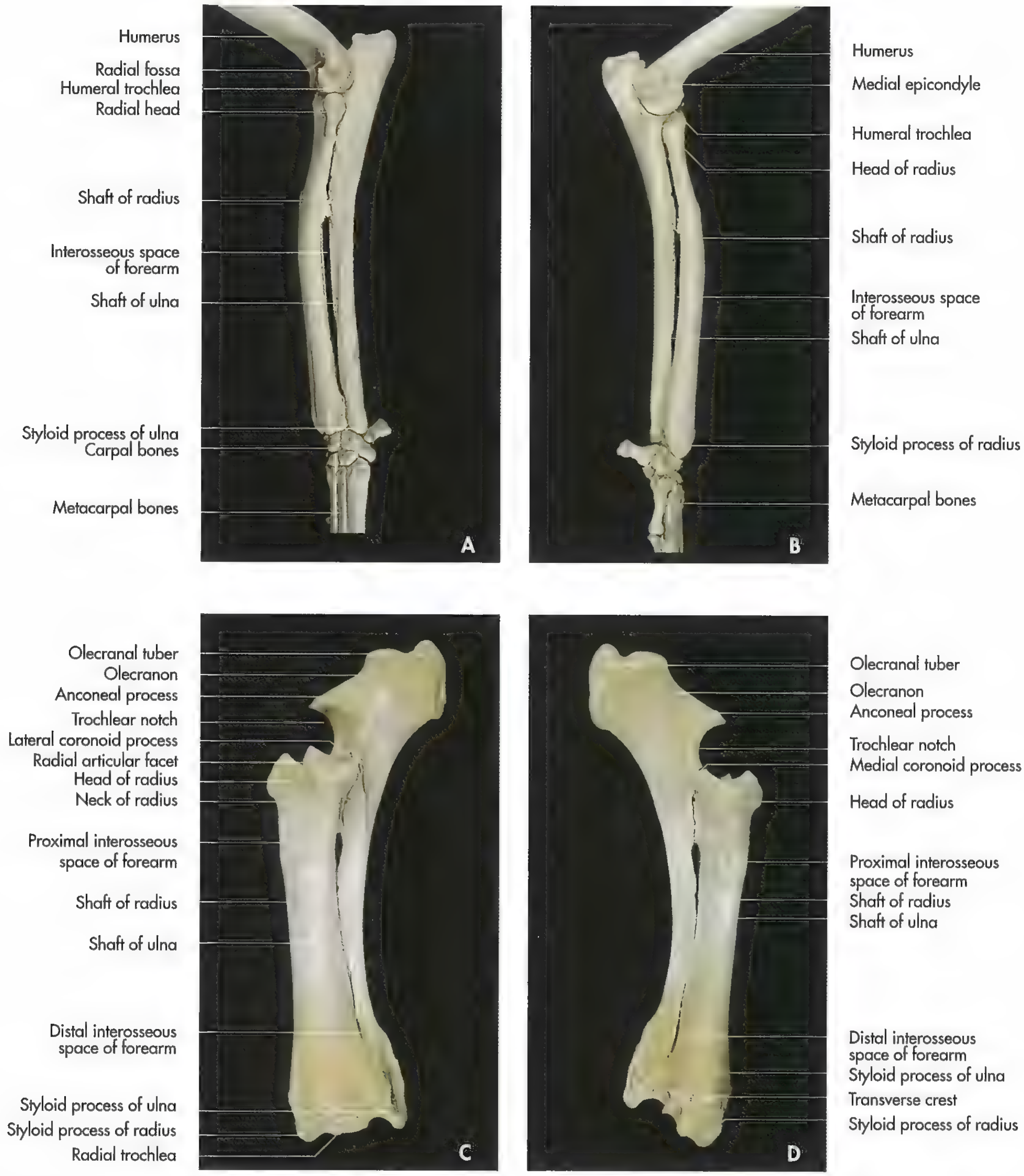

Fig. 3-11. Skeleton of the left forearm (radius and ulna) of a dog (**A** lateral, **B** medial aspect) and an ox (**A** lateral, **B** medial aspect)).

part of the forelimb. The smaller **lateral epicondyle** (epicondylus lateralis) projects caudolaterally and the more prominent **medial epicondyle** (epicondylus medialis) caudomedially. The former gives origin to the extensor muscles, the latter to the flexor muscles of the carpus and digit (Fig. 3-11); both provide attachment for the corresponding **collateral ligament** (ligamenta collateralia) of the elbow joint. The epicondyles are separated by a deep groove, the **olecranon fossa** (fossa olecrani), which contacts with a part of the olecranon. The **radial fossa** (fossa radialis) is situated on the cranial aspect of the condyle. In the dog, the olecranon fossa and the radial fossa communicate through a **supratrochlear foramen** (foramen supratrochleare). In the cat the medial aspect of the distal extremity of the humerus is perforated by the **supracondylar foramen** (foramen supracondylare).

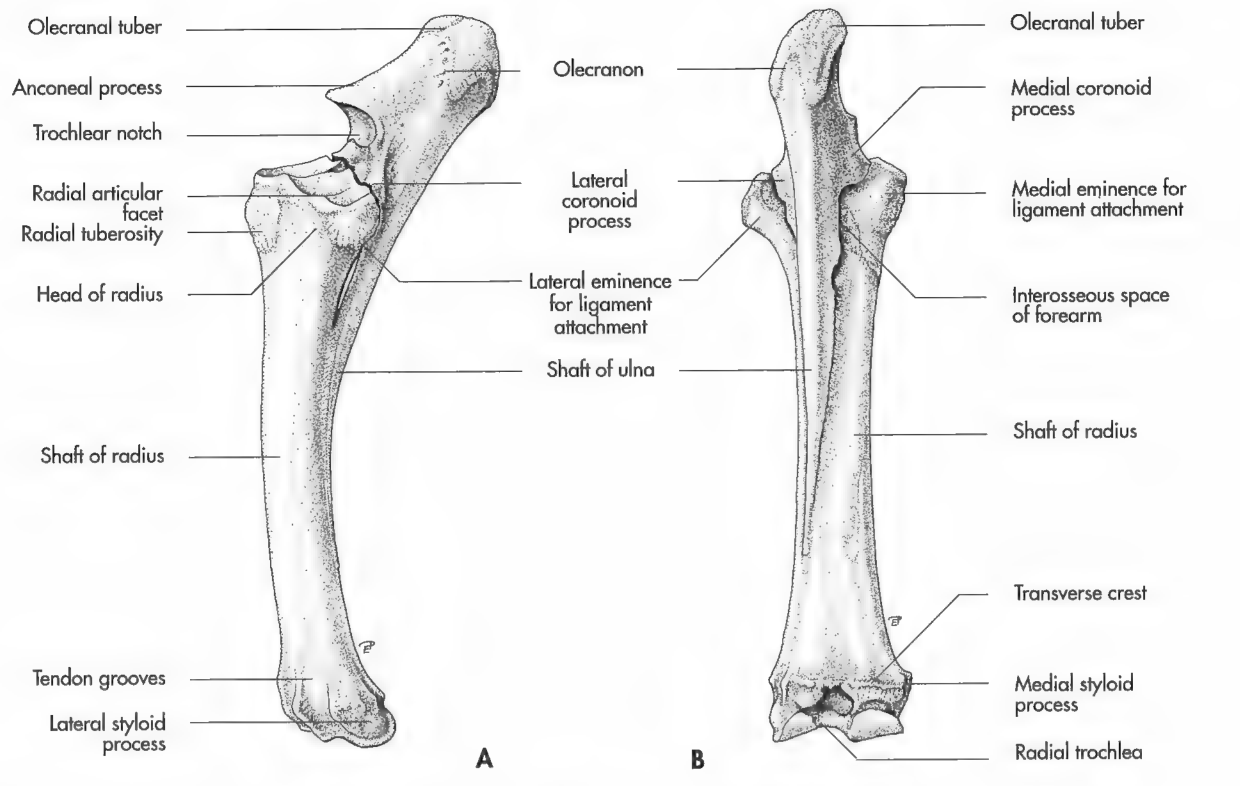

Fig. 3-12. Left radius and right ulna of the horse (schematic, lateral (**A**) and caudal (**B**) aspect).

Skeleton of the forearm (skeleton antebrachii)

The skeleton of the distal part (zeugopodium) of the free appendage of the forelimb consists of two bones, the **radius** and the **ulna** (Fig. 3-2, 3, 11 and 12).

The ulna is placed caudal / caudolateral to the radius in the proximal part of the forearm and lateral in the distal part. Tables 3-3 and 4 show the times of appearance and fusion of the separate ossification centres of the radius and ulna.

During evolution these bones have undergone a species specific development. In man the capacity of rotational movements is well developed: if the palm of the hand is turned backward **(pronation),** the bones of the forearm are in a crossed over position, if the palm of the hand is turned forward **(supination),** radius and ulna are placed parallel to each other. While there is still a limited capacity of movement in carnivores with the dog having a greater limitation to rotation than the cat, no movement is possible in the horse, in which the distal part of the ulna is completely reduced.

During rotation the proximal extremity of the radius is lodged within the **radial notch of the ulna** (incisura radialis ulnae), while the distal extremity rotates around the articular **circumference of the ulna** (circumferentia radialis ulnae). The bones of the forearm allow a 45 degree supination to the dog, which is substantially increased by the rotational capacity of the carpus. In the pig, rotational movement is prevented by

Tab. 3-3. Appearance and fusion of the ossification centres on the radius (Ghetie, 1971).

Species	Primary ossification centres	Additional ossification centres			
		proximal		distal	
	Apperance	Appearance	Fusion	Appearance	Fusion
Horse	2nd month of pregnancy	8th – 9th month of preg.	5th – 18th month	8th month	3½ years
Ox	2nd month of pregnancy	7th – 8th month of preg.	12th – 18th month	7th month	3½ – 4 years
Carnivores	4th week of pregnancy	end of 1st month	8th – 9th month	end of 1st month	1–1½ years

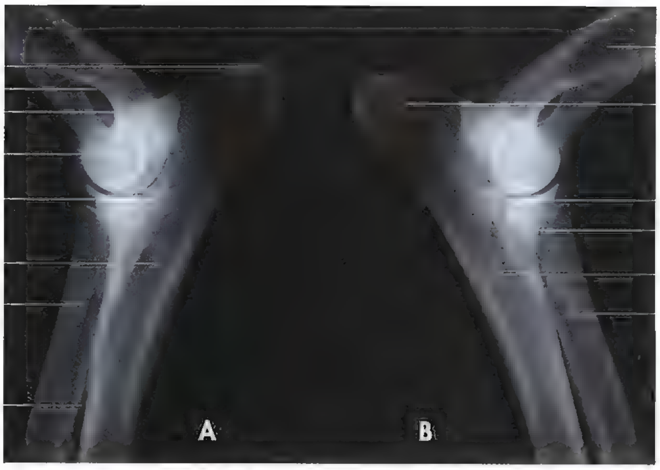

Fig. 3-13. Radiograph of the elbow joint of a dog (**A** mediolateral, **B** lateromedial projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

firm soft tissue bridging of the **interosseous space** (spatium interosseum), in the horse and ox the two bones are fused.

Radius

The radius can be divided into three main segments:

- Proximal extremity carrying the radial head (caput radii),
- Shaft of the radius (corpus radii) and
- Distal extremity bearing the radial trochlea (trochlea radii).

The radius is a rod-shaped bone, that is relatively stronger in ungulates than in carnivores (Fig. 3-11 and 12). The proximal extremity bears the **radial head,** which is transversely widened to present the **radial articular facet** (fovea capitis radii). The articular facet of the radius and the **trochlear notch of the ulna** (incisura trochlearis) articulate with the **condyle of the humerus** (condylus humeri) forming the **elbow joint** (articulatio cubiti) in a species specific way (Fig. 3-5 and 13): in ungulates the radius alone articulates with the humerus, whereas in carnivores the radius is complemented medially by the ulna.

Two eminences protrude lateral and medial to the articular facet of the radial head to give attachment to the ligaments of the joint. At the dorsomedial aspect of the radial head is the **radial tuberosity** (tuberositas radii) to which the biceps muscle tendon inserts. The caudal aspect of the proximal radius presents the **articular circumference** (circumferentia articularis) for the articulation with the ulna to facilitate supination in carnivores. This articular circumference is without function in the horse and ox.

The **shaft of the radius** is compressed in a craniocaudal direction and slightly curved in its length. Its **cranial surface** (facies cranialis) is smooth, its **caudal surface** (facies caudalis) is either roughened (dog and pig) or fused to the ulna. The medial aspect is not covered by musculature and is easily palpable through the skin. The cranial aspect of the distal part of the radial body is grooved for the passage of the extensor tendons. The caudal aspect of the distal radius furnishs origin to the flexor muscles.

The distal extremity forms a trochlea, which is set at right angles to the long axis of the radius and presents the **articular surface towards the carpus** (facies articularis carpea). Proximal to the carpal articular surface of the radius runs a **transverse crest** (crista transversa). The radius extends on the medial side to form the **radial styloid process** (processus styloideus radii) for the insertion of ligaments; in the dog and pig there is a **ulnar notch** (incisura ulnaris radii) on the lateral side. In the ox the distal part of the ulna is completely fused with the radius, in the horse the distal part of the ulna is incorporated within the radius to become the **lateral styloid process** (processus styloideus ulnae).

Ulna

The ulna consists of three main segments:

- Proximal extremity carrying the olecranon,
- Shaft of the ulna (corpus ulnae) and
- Distal extremity with the head of the ulna (caput ulnae).

The **olecranon** and its **tuber** (tuber olecrani) extend the ulna beyond the distal extremity of the humerus. It forms the very prominent point of the elbow and furnishes insertion to the triceps muscle of the forearm.

At the base of the olecranon lies the **trochlear notch** (incisura trochlearis), which supports articulation with the humerus. Overhanging the trochlear notch cranially is the beak-shaped **anconeal process** (processus anconeus), which fits into the **olecranon fossa** (fossa olecrani) of the humerus. To both sides of the anconeal process project the **lateral** and **medial coronoid processes** (processus coronoidei), divided by the **radial notch** (incisura radialis ulnae), which articulates with the **articular circumference of the radius** (circumferentia articularis radii).

The **shaft** is three-sided and smaller than the radial shaft. It runs caudal to the radius and is either attached to it by soft

Tab. 3-4. Appearance and fusion of the ossification centres on the ulna (Ghetie, 1971).

Species	Primary ossification centres	Additional ossification centres			
		proximal		distal	
	Appearance	Appearance	Fusion	Appearance	Fusion
Horse	2nd month of pregnancy	shortly before birth	3½ years	8th–9th month of preg.	2nd–3rd month incl. radius
Ox	2nd month of pregnancy	7th–8th month of preg.	3½–4 years	7th month of preg.	3½ –4 years
Carnivores	4th week of pregnancy	2nd month after birth	10th–14th month	2nd month after birth	12th–15th month

tissue membranes or by bony fusion. Between the shafts of the two bones there are one or more **interosseous spaces** (spatia interossea antebrachii). The fusion of the two bones is nearly complete in the horse and the interosseous space is therefore extremely small.

The **distal extremity** (caput ulnae) continues as the prominent **lateral styloid process** (processus styloideus), which articulates with the proximal row of the carpal bones. In carnivores and pigs it carries the articular circumference for the articulation with the radius. In the horse, the distal extremity is fused to the radius to form the **lateral styloid process** (processus styloideus lateralis).

Skeleton of the manus (skeleton manus)

The skeleton of the manus forms the osseous part of the **autopodium**. The autopodium consists, from proximal to distal, of three segments:

- **Basipodium:** carpal bones (ossa carpi),
- **Metapodium:** metacarpal bones (ossa metacarpalia),
- **Acropodium:** phalanges (ossa digitorum manus).

The phylogenetic changes of the zeugopodium find its continuation in the species specific modifications of the autopodium. The specialisation involves a raising of the manus and pes from the plantigrade posture of humans over the digitigrade posture of carnivores to the unguligrade posture of pig, ox and horse. As the number of the bones are diminished the stoutness of the remaining bones increases. In domestic mammals, only the carnivores show the original pattern of five rays, which is typical for humans, in the pig the rays are reduced to four (2–5), in the ox two rays (3 and 4) are left and in the horse only the third ray remains (Fig. 3-14).

Carpal bones (ossa carpi)

In domestic mammals the carpal bones are arranged in two rows, proximal and distal, each of which typically contains four bones (Fig. 3-14). The proximal row articulates with the radius and ulna in the **antebrachiocarpal joint** (articulatio antebrachiocarpea), the distal row articulates with the metacarpal bones to form the **carpometacarpal joint** (articulatio carpometacarpea) (Fig. 3-5).

The primitive pattern of the carpus contains the following bones:

- **Proximal (antebrachial) row** (mediolateral sequence):
  - Radial carpal bone (os carpi radiale),
  - Intermediate carpal bone (os carpi intermedium),
  - Ulnar carpal bone (os carpi ulnare),
  - Accessory carpal bone (os carpi accessorium).
- **Distal (metacarpal) row** (mediolateral sequence):
  - First carpal bone (os carpale primum, I),
  - Second carpal bone (os carpale secundum, II),
  - Third carpal bone (os carpale tertium, III) and
  - Fourth carpal bone (os carpale quartum, IV).

Fig. 3-14 illustrates the carpal bones present in the different species. In **humans** and **pigs** the original number of **eight carpal bones** is maintained, the **horse has seven or eight carpal bones,** depending on the presence or absence of the first carpal bone. In **carnivores** the radial and intermediate carpal bones are fused, so that the total numbers of carpal bones is reduced to **seven,** although one or two sesamoid bones can be present. **Ruminants** have **six carpal bones,** the first carpal bone is missing and the second and third carpal bones are fused.

Metacarpal bones (ossa metacarpalia)

The original pattern of the skeleton of the metacarpus displays five separate rays. Typically the metacarpus consists of five long bones, the metacarpal bones one (Mc I) to five (Mc V) in mediolateral sequence (Fig. 3-14). All metacarpal bones have the same segments:

- **Proximal extremity** (base, basis) carrying an articular surface for the distal row of the carpal bones and additional facets towards its neighbours and
- a long and species specific **shaft** (body, corpus).
- **Distal extremity** (head, caput) bearing a trochlea for the articulation with the proximal phalanx and various roughenings for ligamentous attachments on both ends.

The phylogenetic reduction in number is compensated for by an increase in stoutness of the remaining bones. This process culminates in the horse, where only the third ray remains

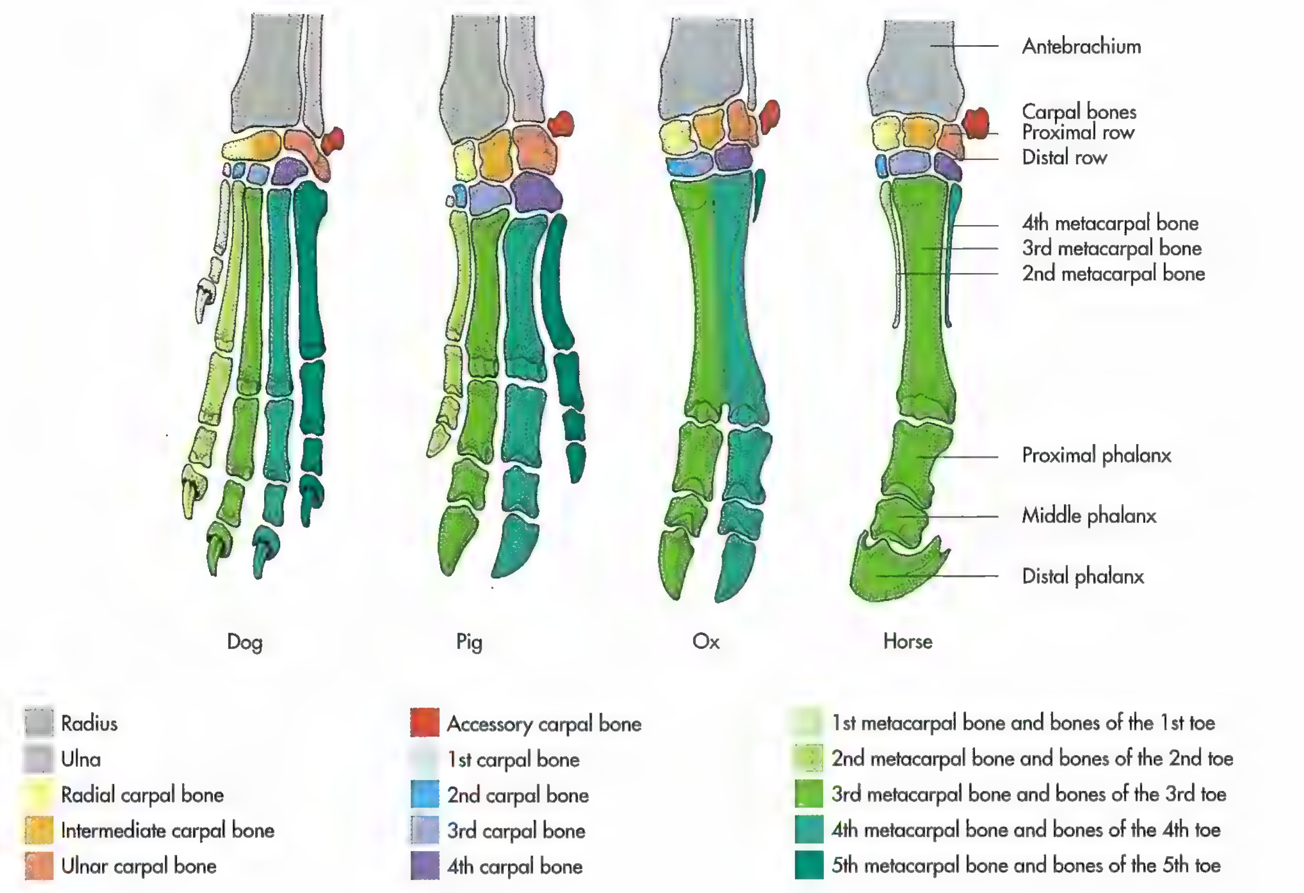

Fig. 3-14. Skeleton of the manus in the domestic mammals (schematic) (Ellenberger and Baum, 1943).

functional. Its axis coincides with the axis of the limb and supports the weight of the horse (mesoaxonic, perissodactyl form). The second and fourth metacarpal bones of the horse are much reduced and do not bear any weight. These bones are commonly called **splint bones** and are situated on either side of the third metacarpal bone (cannon bone).

In the dog, where the weight is supported by the digits only, all five rays are developed. The third and fourth metacarpal bones are the longest and stoutest bones, whereas the first ray is retained as a non-functional dewclaw. The metacarpal bones are opposed closely together and carry flat articular facets facing towards each other on the proximal extremity. The third and fourth are quadrangular, the second and fifth triangular in cross-section.

The metacarpal bones are modified differently in the domestic mammals:

- In **carnivores** the two middle metacarpal bones (Mc III and Mc IV) are the longest. Mc II and Mc V, are shorter and Mc I is most reduced (Fig. 3-15 and 16).
- In the **pig** Mc III and IV are well-developed (artiodactyl form), Mc II and V are reduced and Mc I is missing.
- In **ruminants** Mc III and IV are united on the proximal and middle part to form the large metacarpal bone. The distal extremities articulate separately with the proximal phalanges. Mc V is reduced to become the small metacarpal bone and Mc I and Mc II are lacking.
- In the **horse** only Mc III (cannon bone) is fully developed and carries the single digit (perissodactyl form). Only remnants of Mc II and Mc IV survive as the splint bones, Mc I and Mc V are missing.

Fig. 3-15. Radiograph of the left front foot of a dog (dorsopalmar projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

The original pattern of the phalanges comprises five rays (digiti manus). This pattern has been modified to some degree in all domestic species during evolution. They are designated numerically in mediolateral sequence as first, second, third, fourth and fifth digit. In carnivores all five rays are present, in the pig four rays (2–5), in ruminants two (3 and 4) plus another two non-functional rays (2 and 5) and in the horse only the third ray remains.

The skeleton of a fully developed digit consists of:

- **Proximal (first) phalanx** with a proximal extremity (base, basis), a shaft (body, corpus) and a distal extremity (caput), both extremities exhibit articular facets and prominences for ligamentous attachment.
- **Middle (second) phalanx** shorter, but very similar to the proximal phalanx.
- **Distal (third) phalanx** modified to conform to the hoof or claw that is enclosed within exhibits an articular (facies articularis), a parietal (facies parietalis) and a solar surface (facies solaris).

A number of **sesamoid bones** (ossa sesamoidea) are embedded in the tissues on the palmar aspect of the metacarpophalangeal joint and the distal interphalangeal joint.

Skeleton of the forepaw (manus) in carnivores

Carpal bones (ossa carpi)

The carpal bones are arranged in a proximal and a distal row. The proximal row includes the fused radial and intermediate bone, the intermedioradial bone (os carpi intermedioradiale), the ulnar carpal bone and the accessory carpal bone. The intermedioradial bone articulates with the distal end of the radius (Fig. 3-14 and 16). It has three separate ossification centers, which fuse three to four months after birth. The ulnar carpal bone (os carpi ulnare) is irregular in outline due to a large process, protruding distally. On a dorsopalmar radiograph it becomes superimposed over the accessory carpal bone (Fig. 3-15). The accessory carpal bone is located on the palmar aspect of the carpus and articulates with the radius, the ulna and the ulnar carpal bone. The epiphysis of the accessory carpal bone closes at 4–5 months of age.

The distal row is composed of four carpal bones. They increase in size from the medial to the lateral side and articulate with each other as well as proximally and distally. A sesamoid bone, which can be seen radiographically, is embedded in the tendon of the abductor pollicis longus muscle palmar to the first

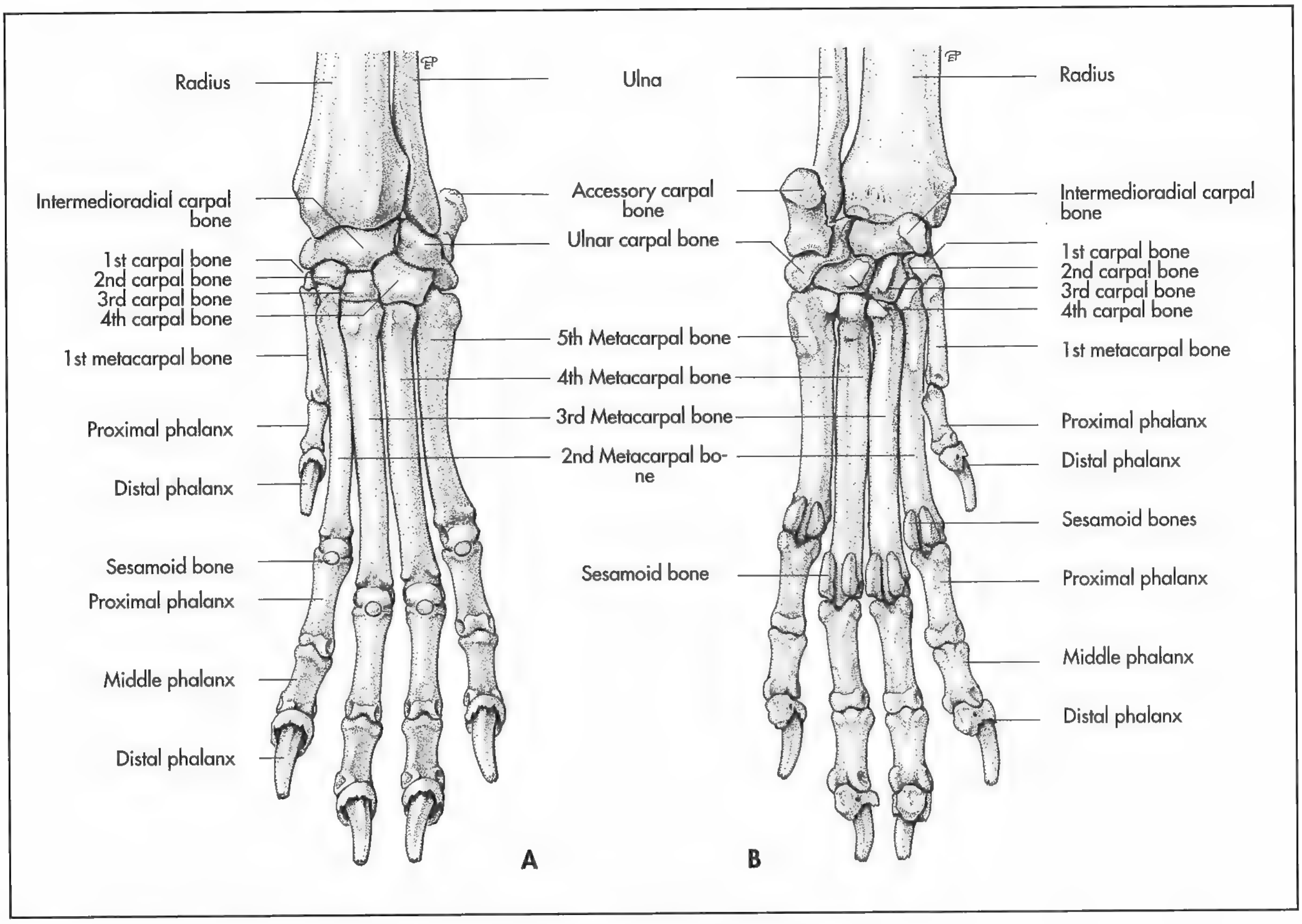

Fig. 3-16. Skeleton of the left forepaw of the dog (schematic, **A** dorsal and **B** palmar aspect).

carpal bone. Another two sesamoid bones may be visible on the palmar aspect between the proximal and distal carpal row.

Metacarpal bones (ossa metacarpalia)

The metacarpus consists of five bones, each of which bears phalanges (Fig. 3-16).

The first metacarpal bone (os metacarpale I) is the shortest, and is relatively stronger in the cat than in the dog. The third and fourth are the longest metacarpal bones and are rounded in the cat and four-sided in the dog. The base of the second and third metacarpal bones bear prominences for ligamentous attachment laterally and all metacarpal bones have these prominences on their distal end bilaterally. The distal extremities bear trochleas, which possesses sharp sagittal crests caudally for the articulation with the sesamoid bones.

Five digits are present in carnivores, with the third and fourth one being the longest and the first digit the shortest (Fig. 3-16). Each digit consist of three phalanges, except the first, which has only two, the proximal and distal phalanx.

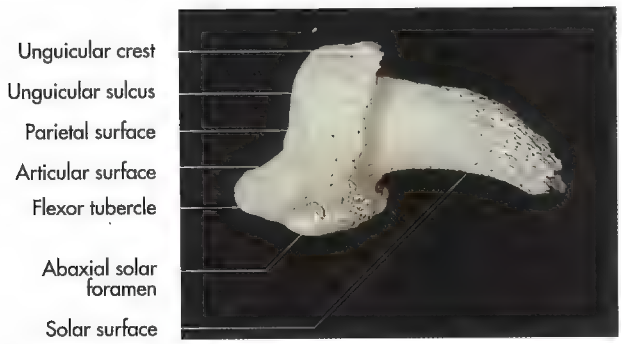

Fig. 3-17. Distal phalanx of a dog (lateral aspect).

Digital skeleton (ossa digitorum manus)

The **distal phalanx** shows a hook-like appearance. It is laterally compressed and drawn out to a sharp point, which is covered by the horny claw (Fig. 3-17). It has a **parietal surface** (facies parietalis), which can be subdivided in two lateral, a palmar surface and a **solar surface** (facies solearis). A **flexor tubercle** (tuberculum flexorium) protrudes on the palmar aspect laterally. Dorsally there is a **unguicular crest** (crista unguicularis) and distally the bone is grooved by the **unguicular sulcus** (sulcus unguicularis). The distal phalanx is fenestrated on each side of the flexor tubercle (foramen soleare axiale et abaxiale). On the palmar aspect of each digit, except the first, at the level of the metacarpophalangeal joints are two sesamoid bones, which can remain cartilagenous.

Fig. 3-18. Radiograph of the left carpus of a horse (lateromedial projection) (courtesy of Prof. Dr. W. Künzel, Vienna).

Fig. 3-19. Radiograph of the left carpus of a horse (dorsopalmar projection) (courtesy of Prof. Dr. W. Künzel, Vienna).

Skeleton of the manus in the horse

Carpal bones (ossa carpi)

The horse shows the original pattern of four carpal bones in the proximal row with the radial carpal bone (os carpi radiale) located medially being the largest bone of this row (Fig. 3-14, 18 and 19). The carpal bones articulate in a complex fashion with each other and with neighbouring bones. The distal row is incomplete, since the first carpal bone (os carpale primum) is missing in the majority of horses. If the first carpal bone is present, it is usually isolated from the rest of the skeleton and embedded in the palmar carpal ligament next to the second carpal bone (os carpale secundum). The third carpal bone (os carpale tertium) has a large articular surface towards the third metacarpal bone (os metacarpale tertium), which distributes the weight of the horse along the long axis of the limb. The second and fourth carpal bones (os carpale secundum, Os carpale quartum) articulate with the proximal extremities of the splint bones.

Metacarpal bones (ossa metacarpalia)

The metacarpus of the horse is composed of the fully developed third metacarpal bone (os metacarpale tertium) and the second and fourth metacarpal bones (os metacarpale secundum, Os metacarpale quartum). The third metacarpal bone (cannon bone) is the only one which carries a digit, whereas the second and fourth metacarpal bones (splint bones) are much reduced. The first and the fifth metacarpal bones are absent (Fig. 3-20).

The **cannon bone** (os metacarpale tertium) is the only weightbearing metacarpal bone. The shaft of the cannon bone is stronger along its medial and dorsal aspects. It is oval in cross section in the forelimbs, with a dorsal and palmar part, and rounded in the hindlimb.

The proximal extremity bears an articular surface for the articulation with the distal row of the carpal bones (facies articularis carpea). Most of this articulation is in the middle part with the third carpal bone, but with smaller amounts of articulation with the second and fourth carpal bones. On each side are two articular facets, which articulate with the proximal ends of the splint bones. The metacarpal tuberosity (tuberositas ossis metacarpalis), which forms the insertion for the extensor carpi radialis muscle, is located dorsomedian on the proximal end of the cannon bone. The distal extremity carries a trochlea, which is subdivided into a slightly larger medial condyle and a smaller lateral one by the sagittal crest.

The **splint bones** (ossa metacarpalia secundum and quartum) extend to the distal third of the cannon bone. The proximal extremities are enlarged and articulate with the distal row of the carpal bones and the cannon bone. The tapering shafts end distally in the easily palpable buttons (Fig. 3-20).

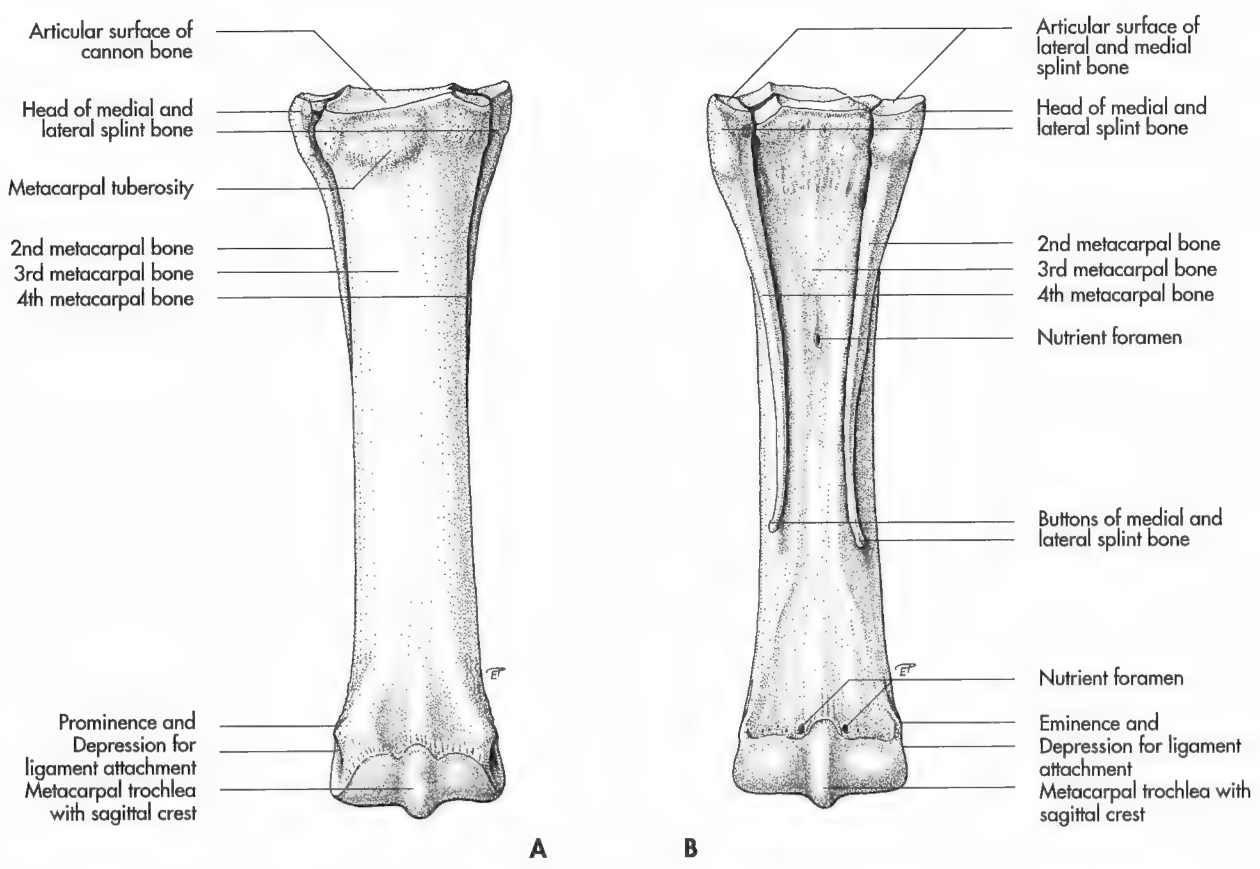

Fig. 3-20. Left metacarpal bones of the horse (schematic, **A** dorsal and **B** palmar aspect).

Digital skeleton (ossa digitorum manus) of the horse

The digital skeleton of the horse is reduced to **one ray**, the third digit (Fig. 3-21, 22 and 23). It consists of three phalanges and the sesamoid bones:

- Proximal (first) phalanx (os compedale, phalanx proximalis),
- Middle (second) phalanx (os coronale, phalanx media),
- Distal (third) phalanx (os ungulare, phalanx distalis),
- Proximal and distal sesamoid bones (ossa sesamoidea proximales et distalis).

The **proximal phalanx** is shaped like a dorsopalmarly compressed cylinder. The proximal end (basis) is wider than its distal end (caput) (Fig. 3-21). The palmar surface shows a rough triangular area (trigonum phalangis proximalis), which is bounded by bony ridges.

The proximal extremity (base) bears an articular surface (fovea articularis), which is subdivided into a larger medial cavity and a smaller lateral one by a sagittal groove. The distal trochlea is adapted for articulation with the proximal articular surface of the middle phalanx.

The **middle phalanx** is very similar to the proximal phalanx (Fig. 3-21). The dorsal articular cavity is divided by a sagittal ridge and corresponds to the distal trochlea of the proximal phalanx. Its dorsal border is elevated to form the extensor process (processus extensorius) and the palmar border thickened to a transverse prominence flexor tuberosity (tuberositas flexoria).

The **distal phalanx** is accompanied by the **lateral and medial cartilage** on each side (cartilago ungularis medialis et lateralis) and the **distal sesamoid bone** (os sesamoideum distale) (Fig. 3-21, 26 and 27). It presents three surfaces and two borders. The **solar border** (margo solearis) separates the **parietal (dorsal) surface** from the **solar (palmar) surface** and the **coronary (proximal) border** (margo coronalis) separates the articular surface from the parietal surface. The coronary border forms a central eminence, the **extensor process** (processus extensorius) (Fig. 3-25). The solar border is notched dorsally (crena marginis solearis).

The palmar aspect of the third phalanx is extended bilaterally by the **medial and lateral palmar processes** (processus palmaris medialis et lateralis). Each process is divided into proximal and distal angles by a notch (incisura processus palmaris) or foramen. The parietal surface is convex from side to side. It is perforated or notched by numerous foramina and grooves for blood vessels and nerves. **Lateral and medial parietal grooves** (sulcus parietalis lateralis et medialis) also

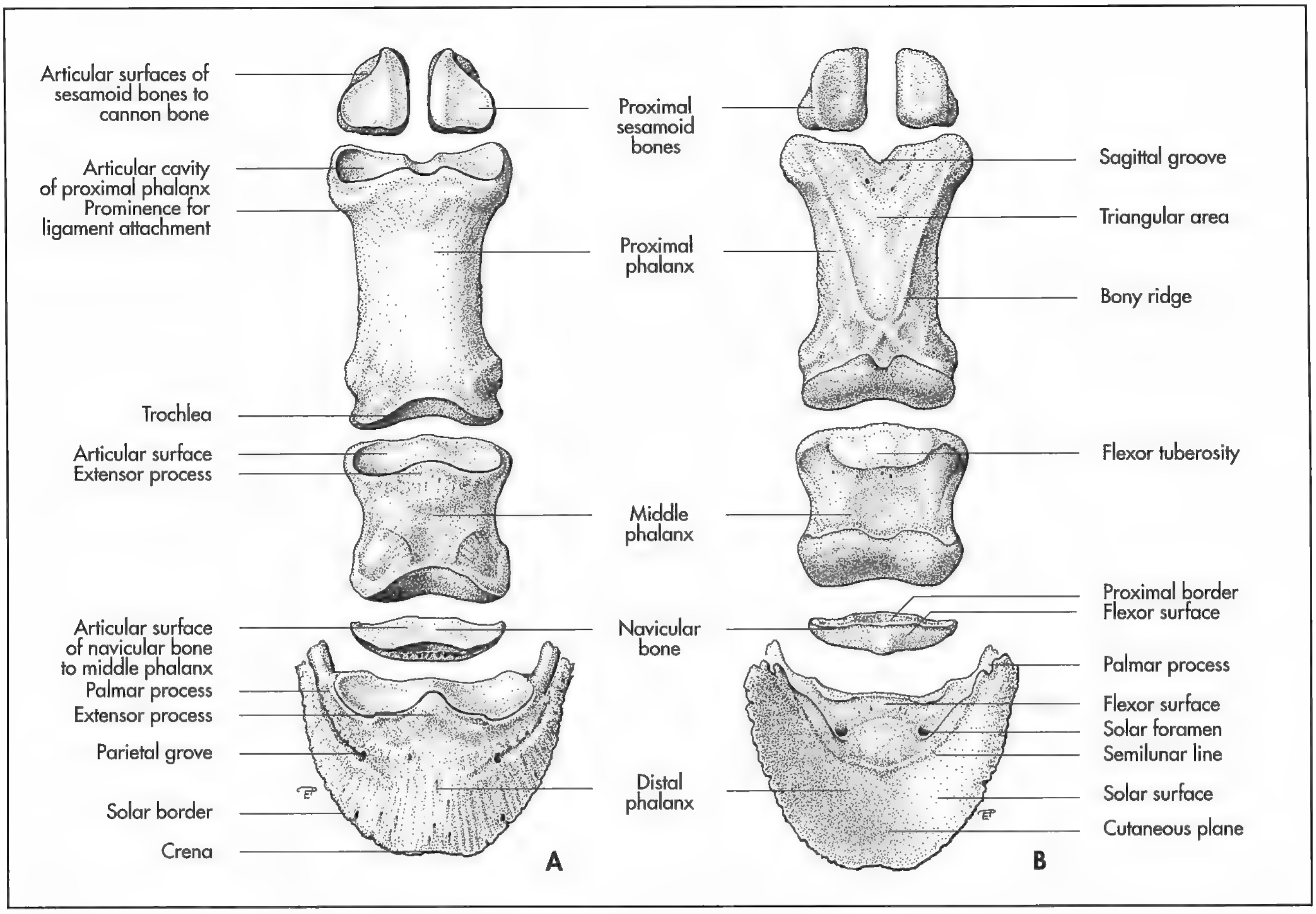

Fig. 3-21. Left digital skeleton of the horse (schematic, **A** dorsal and **B** palmar aspect).

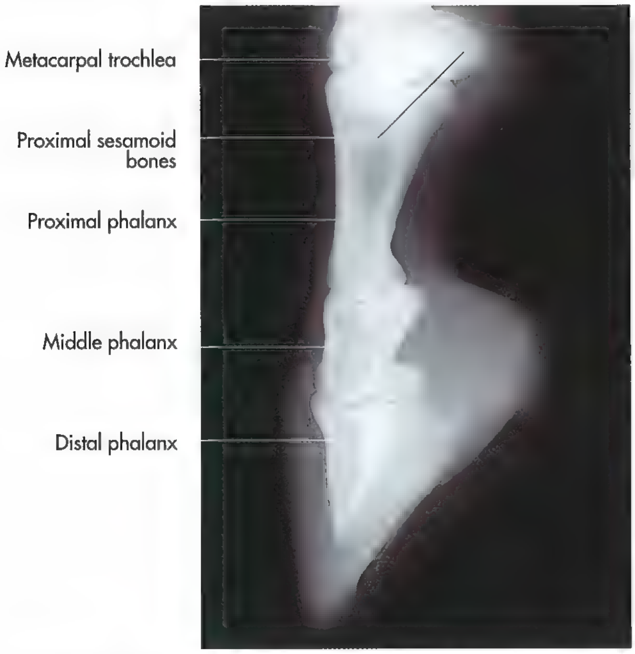

Fig. 3-22. Radiograph of the left digit of a horse (lateromedial projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

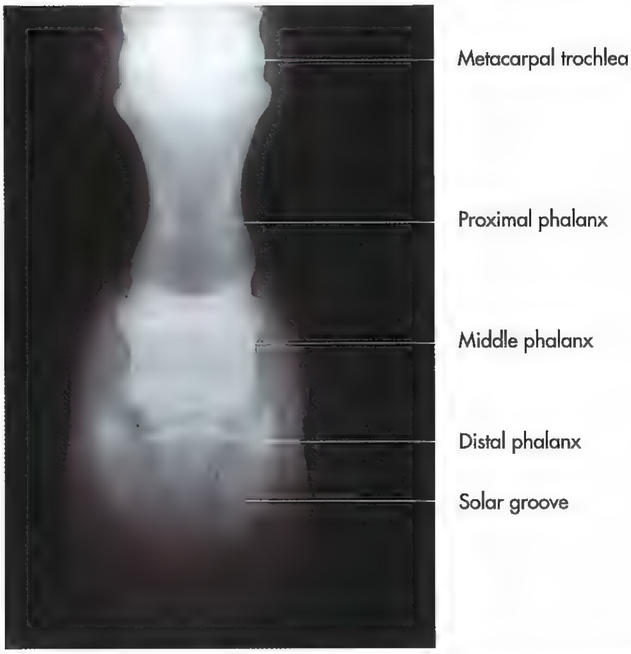

Fig. 3-23. Radiograph of the left digit of a horse (dorsopalmar projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

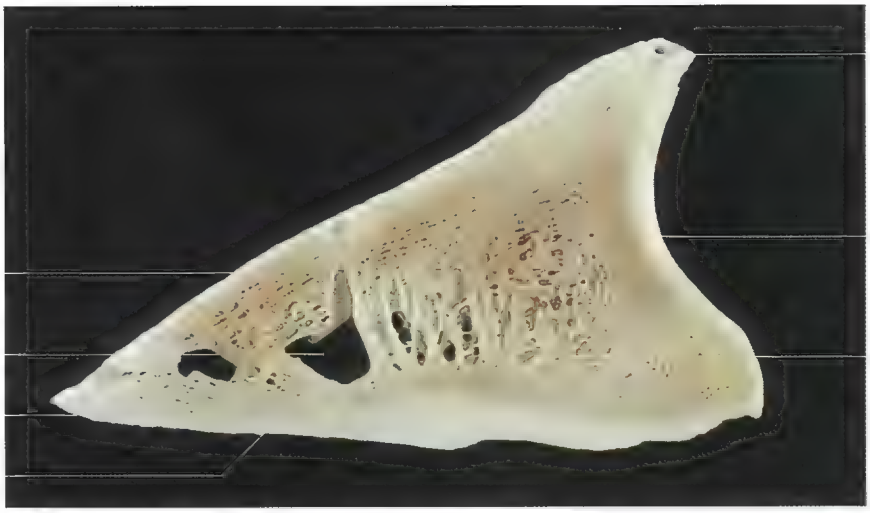

Fig. 3-24. Sagittal section of the distal phalanx of a horse.

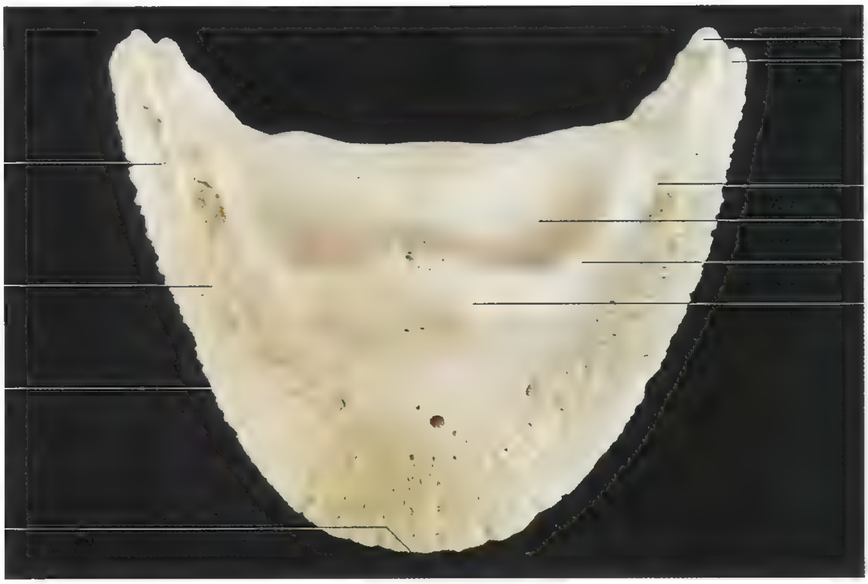

Fig. 3-25. Distal phalanx of a horse (dorsoproximal aspect).

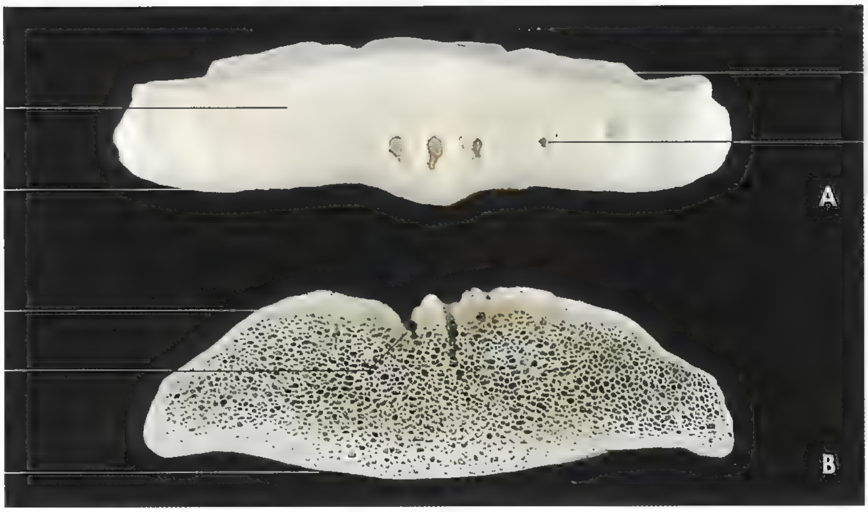

Fig. 3-26. Distal sesamoid bone of a horse (**A** distal aspect and **B** horizontal section).

Fig. 3-27. Distal phalanx of a horse (dorsoproximal aspect).

Fig. 3-28. Distal phalanx and cartilages of a horse (palmarolateral aspect).

encompass blood vessels. A rough **semilunar line** (linea semilunaris) separates the solar surface into a dorsal part (planum cutaneum) and a palmar **flexor surface** (facies flexoria) for the insertion of the deep digital flexor tendon (Fig. 3-21). On either side of the flexor surface is a solar groove which leads to the **solar canal** (canalis solearis). The **articular surface** (facies articularis) articulates with the distal end of the second phalanx proximally and the distal sesamoid bone palmarly.

Two **sesamoid bones** (ossa sesamoidea proximalia) are located just proximal to the fetlock joint on the palmar aspect. They are shaped like a three sided pyramid with their apex pointing proximally. They are firmly attached to each other and the first phalanx by strong ligaments (Fig. 3-21). The dorsal surface is concave and articulates with the distal end of the cannon bone. The abaxial surfaces give attachment to part of the suspensory ligament (m. interosseus medius). The palmar surface is marked by a smooth groove, covered by a layer of cartilage (scutum proximale) for the flexor tendons.

The **distal sesamoid bone** (navicular bone) is boat-shaped with a straight **proximal border** (margo proximalis) and a convex **distal border** (margo distalis) (Fig. 3-21 and 26). The distal border is attached to the third phalanx by a strong ligament. The palmar part of the dorsal navicular articular surface complements the distal surface of the third phalanx. The passage of the deep digital flexor tendon over the palmar surface of the navicular bone is facilitated by fibrous cartilage (scutum distale).

The **cartilages of the third phalanx** (cartilago ungulae medialis et lateralis) are fibrocartilagenous plates, which continue the palmar processes bilaterally (Fig. 3-27 and 28).

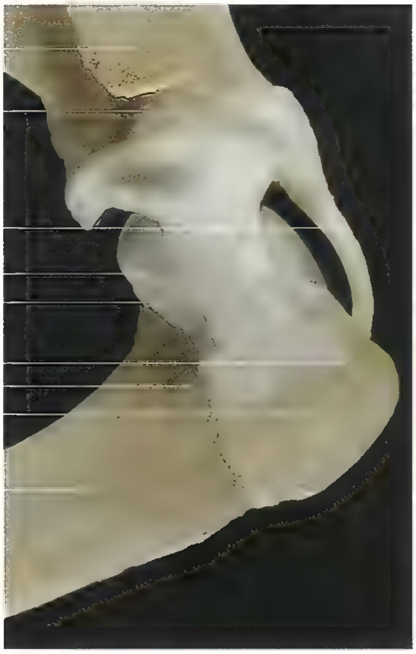

Fig. 3-29. Right shoulder joint of a dog (lateral aspect) (courtesy of Dr. R. Macher, Vienna).

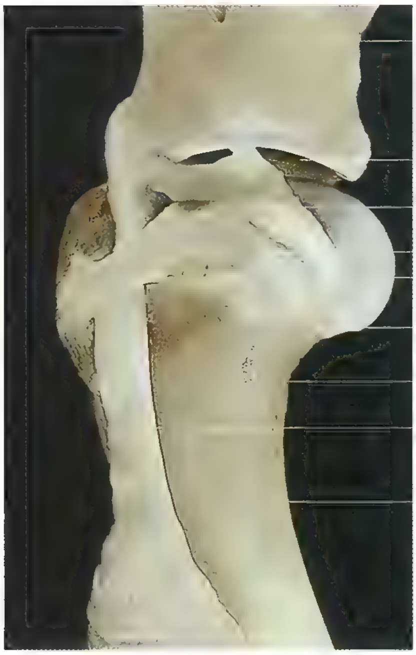

Fig. 3-30 Right shoulder joint of a dog (medial aspect) (courtesy of Dr. R. Macher, Vienna).

The abaxial surface is convex and the axial surface is concave. The distal halves are enclosed in the hoof, but the proximal borders extend to the middle of the pastern.

Joints of the thoracic limb (articulationes membri thoracici)

Articulation of the thoracic limb to the trunk

The forelimb is joined to the axial skeleton by an arrangement of muscles, tendons and fascia (synsarcosis), without forming a conventional joint.

Shoulder or humeral joint (articulatio humeri)

The shoulder joint links the considerably smaller **glenoid cavity** (cavitas glenoidalis) of the scapula to the larger **humeral head** (caput humeri) (Fig. 3-29 and 30). The edge of the glenoid cavity is extended by the fibrocartilagenous **glenoid lip** (labrum glenoidale), which deepens the otherwise shallow glenoid cavity.

While the shoulder joint is a typical **spheroidal joint** (articulatio spheroidea) in structure and should theoretically have a considerable versatility of movement, its actual range of movement is limited by the surrounding muscles and it therefore functions as a hinge joint with the primary movements being flexion and extension. Rotation, adduction and abduction are restricted, but possible especially in carnivores, in which abduction of 60°, pronation of 35° and supination of 45° is possible. In the horse, lateral and medial movements are almost impossible due to the cylindrical shape of the humeral head.

Due to the absence of collateral ligaments of the shoulder, tendons and muscles act as ligaments and support the joint. The tendon of the subscapular muscle acts as the medial collateral ligament and the tendon of the infraspinous muscle acts as the lateral collateral ligament.

The **joint capsule** (capsula articularis) is spacious and blends, in some areas, with the tendons of the surrounding muscles, particularly the subscapular muscle. The joint consists of three cranial and two caudolateral pouches in the horse and ox (Fig. 3-31 and 32) and two cranial pouches and one caudolateral pouch in carnivores (Fig. 3-33 and 34).

The joint capsule obtains its strength internally by fibrous and collagenous bands: the **medial** and **lateral glenohumeral ligaments** (ligamenta glenohumerale lateralis et medialis) (Fig. 3-29). In ungulates there is an additional band, the **coracohumeral ligament** (ligamentum coracohumerale) incorporated in the joint capsule between the supraglenoid tubercle and the greater tubercle. In carnivores the transverse humeral ligament (ligamentum transversum humeri) bridges the bicipital groove and holds the like-named tendon in place (Fig. 3-30). Part of the joint capsule surrounds the bicipital tendon in the intertubercular groove and forms a synovial sheath (vagina synovialis intertubercularis) in carnivores, the pig and the sheep.

In the horse and ox the tendon sheath is replaced by the **intertubercular bursa** (bursa intertubercularis), which does not communicate with the cavity of the shoulder joint.

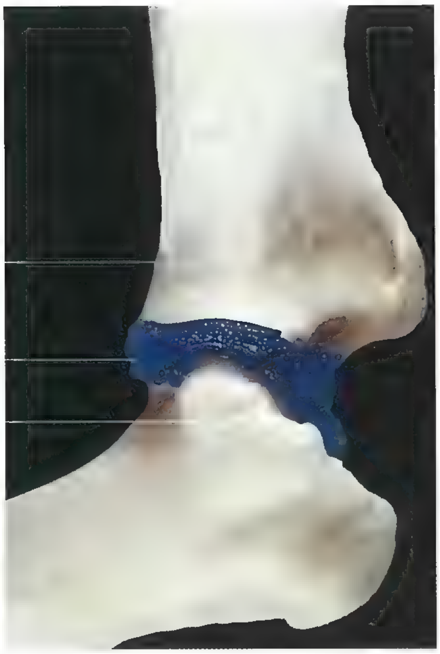

Fig. 3-31. Acrylic cast of the left shoulder joint of a horse (medial aspect) (courtesy of Dr. R. Böhmisch, Munich).

Fig. 3-32. Acrylic cast of the left shoulder joint of a horse (caudal aspect) (courtesy of Dr. R. Böhmisch, Munich).

Fig. 3-33. Acrylic cast of the right shoulder joint of a dog (lateral aspect) (courtesy of Dr. K. Ganzberger, Vienna).

Fig. 3-34. Acrylic cast of the right shoulder joint of a dog (medial aspect) (courtesy of Dr. K. Ganzberger, Vienna).

Injection sites

- **Dog:** The dog is put in lateral recumbency with the joint slightly flexed. The needle is inserted directly caudal and proximal to the greater tubercle. It is advanced in a horizontal plane in a mediocaudal direction.
- **Cat:** The cat is in lateral recumbency, the joint slightly flexed. The needle is inserted cranial to the tendon of the infraspinous muscle, just distal to the suprahamatus process and advanced about 1 cm until it reaches the glenoid cavity.
- **Pig:** The pig is in lateral recumbency with the joint slightly flexed. The needle is inserted on the cranial border of the tendon of the infraspinous muscle at the level of the greater tubercle and advanced in a mediocaudal and slightly distal direction.
- **Horse** and **ox:** A 10 cm needle is inserted into the palpable depression between the cranial and caudal eminence of the greater tubercle of the humerus. The needle is directed in a frontal plane in a caudal and slightly medial direction.

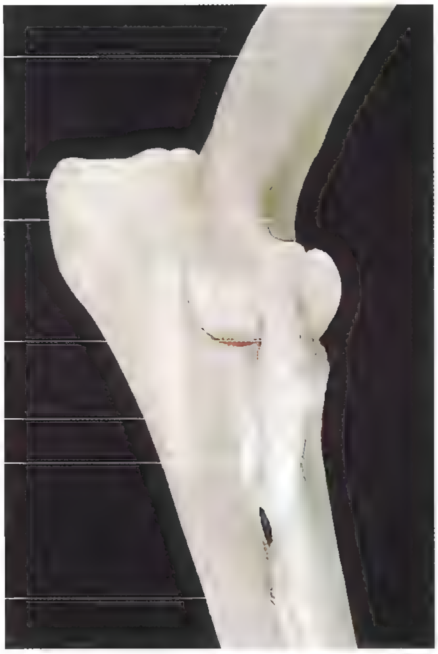

Fig. 3-35. Right elbow joint of a dog (lateral aspect) (courtesy of Dr. R. Macher, Vienna).

Fig. 3-36. Right elbow joint of a dog, maximally flexed (lateral aspect) (courtesy of Dr. R. Macher, Vienna).

Fig. 3-37. Acrylic cast of the right elbow joint of a dog, (medial aspect) (courtesy of Dr. R. Macher, Vienna).

Fig. 3-38. Acrylic cast of the right elbow joint of a dog, (lateral aspect) (courtesy of Dr. R. Macher, Vienna).

Elbow joint (articulatio cubiti)

The elbow joint (humeroulnar joint, articulatio humeroulnaris) is a **composite joint,** formed by the humeral condyle (condylus humeri) with the trochlear notch of the ulna (incisura trochlearis ulnae) and the radial head (caput radialis).

The elbow joint is a typical **hinge joint or ginglymus,** with the range of movements restricted to flexion and extension in a sagittal plane. Prominent ridges and grooves on the trochlear surface and the protrusion of the olecranon into the olecranon fossa of the humerus prevent lateral or rotational movements. In the cat the range of movement in the sagittal plane is limited to 140°. In the dog between 100° and 140° of extension is possible, depending on the breed. In the horse, and to a lesser degree in carnivores and cattle the elbow joint acts as a snap joint. This is caused by the eccentric proximal insertion of the collateral ligaments in relation to the axis of movement of the joint.

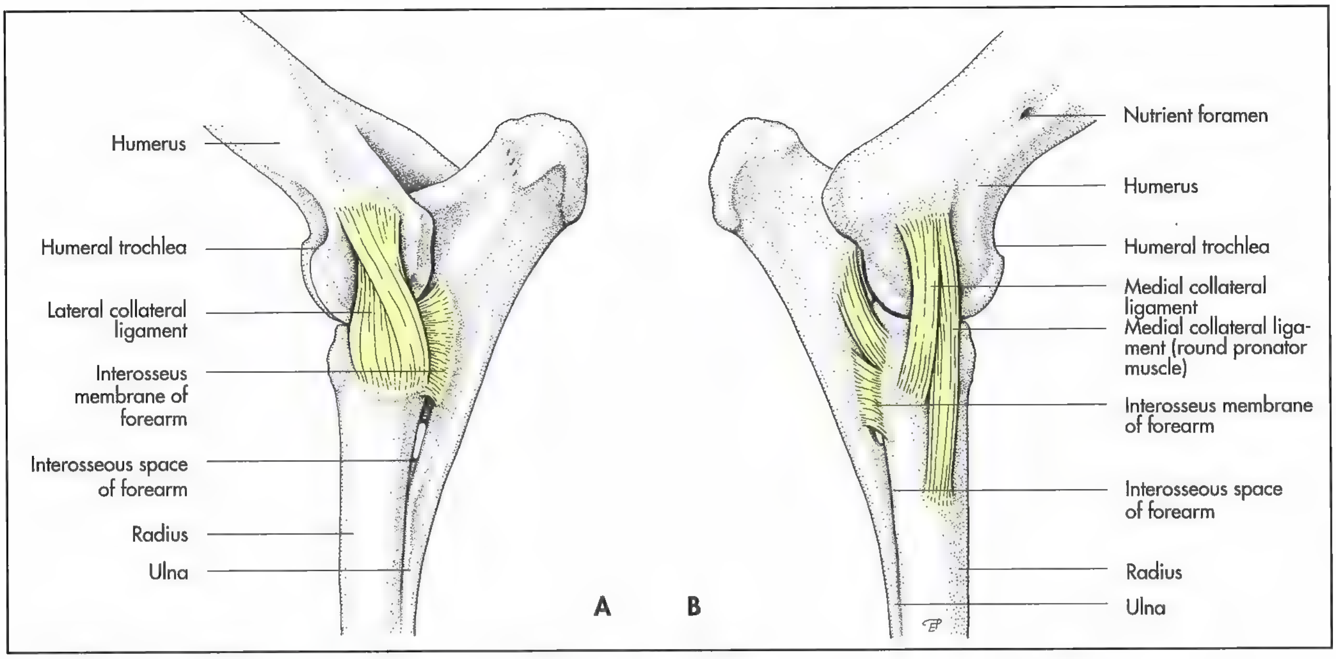

Fig. 3-39. Left elbow joint of the horse (schematic, **A** lateral and **B** medial aspect).

Fig. 3-40. Acrylic cast of the right elbow joint of a dog (craniolateral aspect) (courtesy of Dr. W. Kaser, Munich).

Fig. 3-41. Acrylic cast of the right elbow joint of a dog (cranial aspect) (courtesy of Dr. W. Kaser, Munich).

Strong collateral ligaments extend from the lateral and medial humeral epicondyle to the radius and ulna:

- **Lateral (radial) collateral ligament** (ligamentum collaterale cubiti laterale) is attached proximally to the lateral epicondyle of the humerus and divides further distally into a stronger cranial part, inserting on the radius and a more slender caudal part, inserting on the ulna. The caudal (ulnar) part is absent in the horse.
- **Medial (ulnar) collateral ligament** (ligamentum collaterale cubiti mediale) is attached proximally to the medial epicondyle of the humerus and inserts with two parts on the ulna and radius. In horses and cattle the cranial part of this ligament represents the remnant of the pronator teres muscle.
- **Olecranon ligament** (ligamentum olecrani) extends between the medial epicondyle of the humerus and the anconeal process and re-enforces the joint capsule on its flexor aspect in the cat and dog (Fig. 3-37).

The humeroulnar, humeroradial and the proximal radioulnar joint (articulatio radioulnaris proximalis) share a common joint

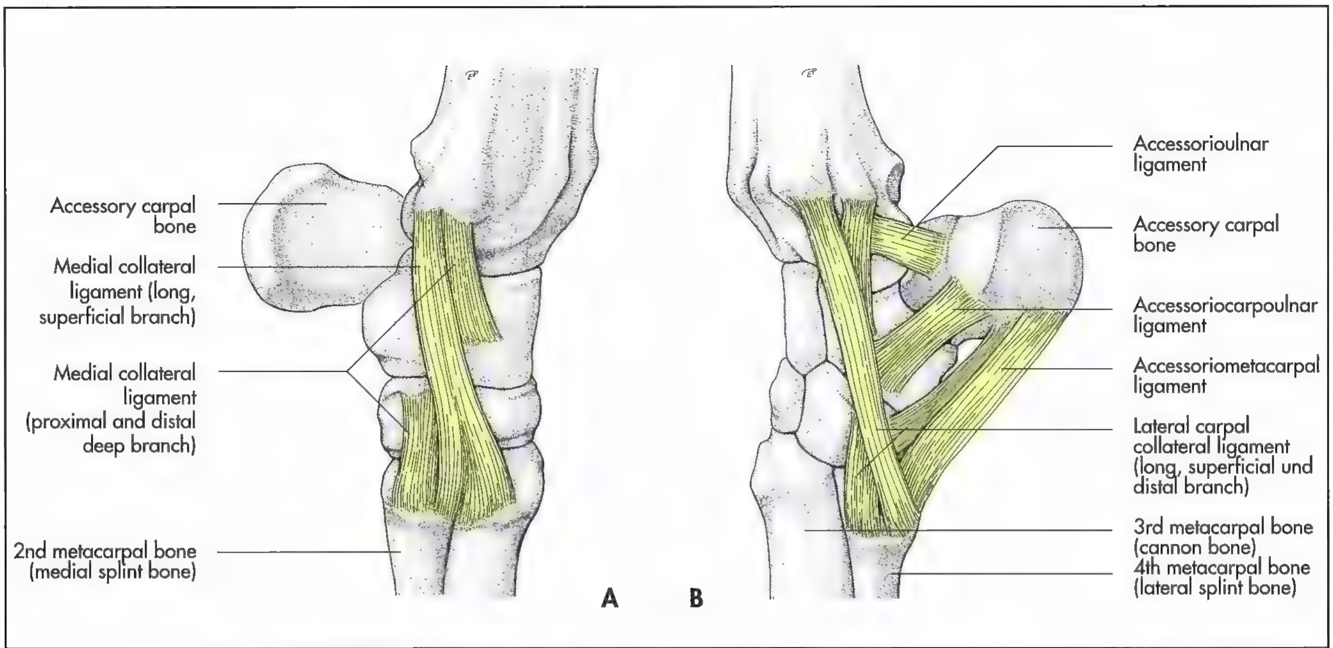

Fig. 3-42. Long collateral ligaments and ligaments of the accessory carpal bone of the left carpus of the horse (schematic, **A** medial and **B** lateral aspect) (courtesy of Dr. Susanne Wagner, Vienna).

capsule (capsula articularis) (Fig. 3-37 and 40). On the caudal aspect, the capsule inserts along the proximal border of the olecranon fossa. On the cranial aspect one pouch extends medially under the biceps muscle and one laterally under the common digital extensor muscle.

Injection sites

- **Dog** and **cat:** The animal is in lateral recumbency with the joint flexed at 90°. The needle is inserted between the lateral epicondyle and the olecranon and advanced in a craniomedial direction.
- **Pig:** The needle is inserted into the palpable depression just caudal to the lateral epicondyle in a craniomedial direction.
- **Ox:** A 6 cm needle is inserted between the lateral collateral ligament and the tendon of origin of the ulnar extensor muscle of the carpus and advanced horizontally.
- **Horse:** A 4 cm needle is inserted from the lateral side just cranial or caudal to the lateral collateral ligament of the joint and half way between the lateral humeral epicondyle and the lateral tuberosity of the proximal aspect of the radius. The needle is advanced in a horizontal plane in a slightly proximomedial direction.

Radioulnar articulations (articulatio radioulnaris proximalis et articulatio radioulnaris distalis)

The capacity of rotational movements of the two forearm bones is lost in large animals and reduced in carnivores caused by the species specific reduction of the ulna. About 100° of supination is allowed to the cat and 50° to the dog. In the horse and in cattle the proximal parts of the radius and ulna are united by fibrous and elastic tissues which undergo ossification with advancing age (synchondrosis).

The radius and ulna of the pig articulate firmly proximally and distally (amphiarthrosis).

In carnivores there are two separate synovial radioulnar articulations:

- **Proximal radioulnar joint** (articulatio radioulnaris proximalis), which is formed by the articular circumference of the radius (circumferentia articularis proximalis radii) and the radial notch of the ulna (incisura radialis ulnae).
- **Distal radioulnar joint** (articulatio radioulnaris distalis, which is formed by the articular circumference of the ulna (circumferentia articularis proximalis ulnae) and the ulnar notch of the radius (incisura radialis ulnae).

The proximal radioulnar joint is supported by several ligaments:

- **Annular ligament of the radius** (ligamentum anulare radii) passes around the radial head on the flexor aspect of the elbow joint, lying under the collateral ligaments and attaches distally to the radial notch of the ulna.
- **Interosseous ligament of the antebrachium** (ligamentum interosseum antebrachii) bridges the proximal half of the interosseous space in the dog and strengthens the interosseous membrane laterally.
- **Interosseous membrane of the antebrachium** (membrana interossea antebrachii) is a soft tissue membrane. It joins the radius to the ulna in carnivores and juvenile large animals. This membrane becomes ossified in adult ungulates.

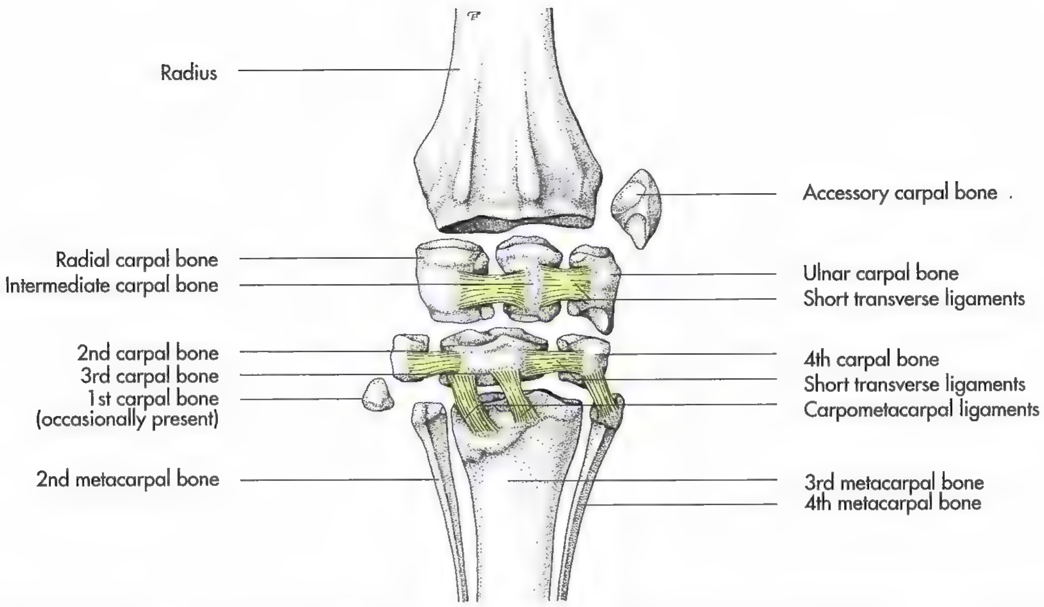

Fig. 3-43. Short ligaments of the left carpus of the horse, with the joint spaces extended (schematic, dorsal aspect) (courtesy of Dr. Susanne Wagner, Vienna).

The single ligament of the distal radioulnar joint, the **radioulnar ligament** (ligamentum radioulnare) extends between the radial trochlea and the styloid process of the ulna. It is a distinct ligament in dogs, whereas in cats it consists of fibres embedded in the joint capsule.

The proximal radioulnar joint communicates freely with the main elbow joint, the distal radioulnar joint is a proximal extension of the antebrachiocarpal joint in carnivores and in the pig.

Articulations of the manus (articulationes manus)

Carpal joints (articulationes carpeae)

The carpal joints are **composite articulations,** that include the following joints:

- **Ulnarcarpal and radiocarpal joint** (articulationes antebrachiocarpea), between the radius and ulna and the proximal carpal bones,
- **Middle carpal joint** (articulationes metarcarpeae), between proximal and distal carpal bones,
- **Intercarpal joint** (articulationes intercarpeae), between the individual carpal bones of each row and
- **Carpometacarpal joints** (articulationes carpometacarpeae), between the distal carpal bones and the metacarpal bones.

Although the three levels of articulation share a common fibrous capsule, the synovial compartments are separate except for a communication between the middle and the distal joints. The joint capsule is loose at the level of the proximal joints and becomes narrower distally.

While the carpus as a whole acts as a **hinge joint,** the single joint surfaces allow different ranges of movement (Fig. 3-24). Most movement occurs at the proximal articulation, considerable movement is possible at the middle articulation, but virtually no movement takes place at the distal articulation.

The **antebrachiocarpal joint** consists of the **radiocarpal joint** (articulatio radiocarpea) and the **ulnocarpal joint** (articulatio ulnocarpea).

This joint can be regarded as a hinge joint in the horse, a cochlear joint in ruminants and a ellipsoidal joint in carnivores, where, in addition to the hinge movement, abduction and adduction are possible.

Less movement takes place in the **middle carpal joint,** which is also a **complex hinge joint.** It is formed between the proximal (ulnar, intermediate and radial carpal bone) and distal row (carpal bones I to V) of the carpal bones. It also includes the accessory carpal joints: The intercarpal joints are firm articulations formed by the adjacent articulating surfaces of the same row and have a very limited range of movement.

The **carpometacarpal joints,** located between the distal carpal bones and the metacarpal bones are **plane joints,** which do not allow any significant movement. Many distinct **ligaments** and several **fibrous bands** of the joint capsule support the carpus. The ligaments can be divided into two major groups:

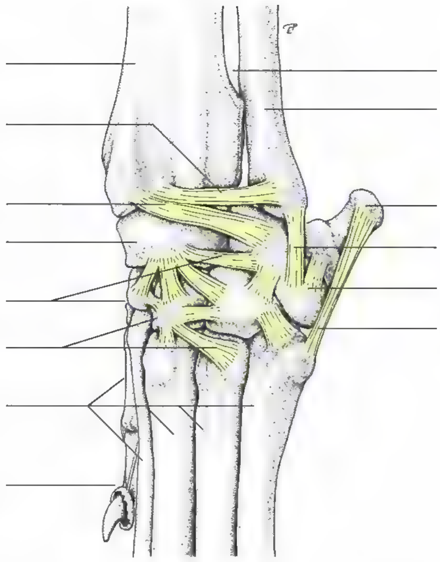

Fig. 3-44. Ligaments of the left carpus of the dog (schematic, lateral aspect) (Ghetie, 1954).

- Long lateral and medial collateral ligaments (ligamenta collateralia carpi) extending between the forearm and the metacarpus,
- Short ligaments, joining neighbouring bones of the same row or adjacent rows.

The **lateral collateral ligament** (ligamentum collaterale carpi laterale) attaches proximally to the lateral styloid process of the radius and divides into a superficial branch, which inserts at the proximal extremity of the lateral metacarpal bone and two deep branches, which insert at the ulnar carpal bone and the fourth carpal bone.

The **medial collateral ligament** (ligamentum collaterale carpi mediale) extends between the medial styloid process of the radius and the proximal extremity of the medial metacarpal bone. A deep branch is detached to the second carpal bone.

In carnivores, the long continuous collateral ligaments are absent, and only the antebrachiocarpal joint is bridged by medial and lateral collateral ligaments. The anatomy of the short carpal ligaments is rather complex and will not be described in detail. The **short ligaments** can be subdivided into three groups:

- **Vertical ligaments** bridging the chief joints,
- **Horizontal ligaments,** which join the neighbouring bones of the same row,
- **Short ligaments** connecting the accessory carpal bone to the ulna, the ulnar carpal bone, the fourth carpal bone and the fourth and fifth metacarpal bones.

The fibrous layer of the joint capsule is strengthened dorsally by the **extensor retinaculum** (retinaculum extensorum), which surrounds the extensor tendons. The **flexor retinaculum** (retinaculum flexorum) enforces the carpus on the palmar aspect. It attaches to the base of the accessory bone and passes medially to become part of the metacarpal fascia.The carpal canal is formed superficially by the flexor retinaculum and deeply by the joint capsule of the carpus. It contains the flexor tendons, arteries and nerves.

Due to the complex anatomy of the carpal skeleton complemented by the numerous ligaments of the carpus, the primary movements of the carpal joints are flexion and extension. Whilst in full extension the carpus forms a single axis with the metacarpus and in full flexion the carpus enables the digits to touch the forearm. Slight lateral and medial movements are possible, particularly in carnivores (up to 30°). In addition the whole joint acts as a shock absorber.

Injection sites

- **Dog** and **cat:** antebrachiocarpal joint and midcarpal joint: The animal is in lateral recumbency, the joint flexed in a 90° angle. The needle is inserted from the dorsolateral side in the proximal pouch between the common digital extensor tendon and the radial extensor muscle at the level of the joints. Separate injection of the carpometacarpal joint is unnecessary due to its communication with the midcarpal joint.
- **Pig:** The pig is put in lateral recumbency and the joint flexed. For the injection of the antebrachiocarpal joint the needle is inserted into the dorsal pouch of the joint capsule lateral to the radial extensor muscle in a horizontal plane and palmar direction. The midcarpal and carpometacarpal joint is injected just dorsal to the medial collateral ligament into the palpable joint space.
- **Ox:** A 4 cm needle is inserted on the dorsolateral aspect between the lateral collateral ligament and the radial extensor muscle with the carpus flexed. The needle is advanced horizontally.

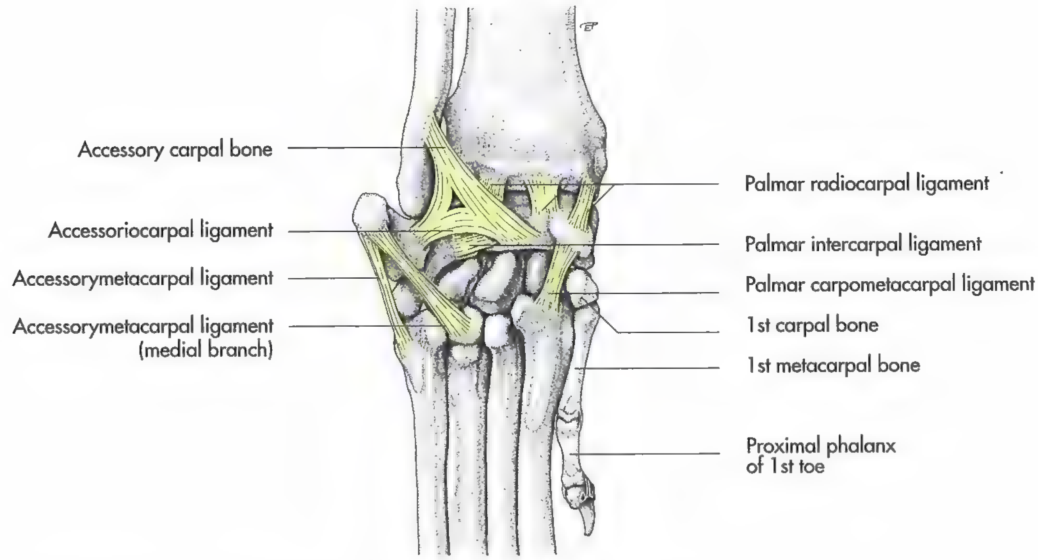

Fig. 3-45. Ligaments of the left carpus of the dog (schematic, palmar aspect (Ghetie, 1954).

- **Horse:** Antebrachiocarpal joint and midcarpal joint: The carpus is flexed and the joint is entered horizontally with a 3 cm needle in the palpable depressions between the radial extensor muscle and the common digital extensor tendons on the dorsal aspect of the joint at the level of the articulation. Separate injection of the carpometacarpal joint is unnecessary due to its communication with the midcarpal joint.

Intermetacarpal joints (articulationes intermetacarpeae)

The **metacarpal bones** articulate with each other at their proximal ends in carnivores and in the pig. In ruminants the remaining third and fourth metacarpal bones are fused and no movement is possible. Although there are small joints between the proximal ends of the splint bones and the cannon bone in the horse, movement is very limited, due to the interosseous ligament between the shaft of the metacarpal bones, which undergoes ossification.

Phalangeal joints

Each digit has **three articulations**:

- Metacarpophalangeal joints (articulationes metacarpophalangeae),
- Proximal interphalangeal joints (articulationes interphalangeae proximales manus) and
- Distal interphalangeal joints (articulationes interphalangeae distales manus).

The **metacarpophalangeal joints** are hinge joints between the distal end of the metacarpal bones and the proximal ends of the first phalanges and the proximal sesamoid bones. The joint capsules form **dorsal and palmar pouches** (recessus dorsales et recessus palmares) (Fig. 3-46). Ligaments exist in the form of collateral ligaments, sesamoidean ligaments and interdigital ligaments in animals with more than one ray. The sesamoidean ligaments can be subdivided into proximal, middle and distal ligaments. The proximal ligament is replaced by the interosseous muscles or in the case of ruminants and horses by the suspensory ligament, the tendinous remnant of the medial interosseous muscle.

The **proximal interphalangeal joints** are formed by the distal ends of the first phalanges and the proximal ends of the middle phalanges. They are classified as saddle joints due to the concavo-convex shape of the joint surfaces and act as hinge joints, allowing a limited range of lateral movements. Each joint has a capsule with dorsal and palmar pouches, collateral ligaments (horse) or palmar ligaments (pig and ruminants) or both (carnivores).

The **distal interphalangeal joints** are very similar to the proximal interphalangeal joints.

Phalangeal joints of the carnivores

Metacarpophalangeal joints

Carnivores have five metacarpophalangeal joints corresponding to the number of digits. They are formed by the distal trochlea of the metacarpal bones I to V and the proximal articular surface of the first phalanges together with two proximal sesamoid bones for each joint. In addition to flexion and extension, these joints allow a considerable degree of abduction and adduction. Each joint has a spacious joint capsule with a dorsal and palmar pouch. The dorsal pouches are thickened by a band of cartilage. The proximal sesamoid bones are interspersed in the palmar part of the joint capsule.

The ligaments can be divided into:

- **Collateral ligaments** (ligamenta collateralia mediale and laterale) between the distal ends of the metacarpal bones and the first phalanges.
- **Ligaments of the proximal sesamoidean bones:**
  - **proximal ligaments:** replaced by the interosseous muscles,
  - **middle ligaments:** intersesamoidean ligaments, uniting the palmar surfaces of the paired sesamoid bones of one digit and the lateral and medial sesamoidean ligaments between the sesamoid bones and the metacarpal bones and the proximal phalanges and
  - **distal ligaments:** the short distal sesamoidean ligament and the cruciate ligaments of the sesamoidean bones between the proximal sesamoidean bones and the proximal phalanges.

Proximal interphalangeal joints

The proximal interphalangeal joints are formed by the distal ends of the proximal phalanges and the proximal articular fossae of the middle phalanges II to V. The first digit does not have a proximal interphalangeal joint. These are saddle joints with a maximal extension of 90° and a maximal flexion of 60°. The joint capsules are similar to the ones of metacarpophalangeal joints with dorsal and palmar pouches and a cartilagenous enforcement dorsally. Collateral ligaments (ligamentum collaterale laterale et mediale) are the only ligaments bridging the joint vertically on the lateral and medial aspects.

Distal interphalangeal joints

The distal interphalangeal joints are saddle joints, formed by the distal trochlea of the medial phalanges and the articulating fossae of the distal phalanges.

The joint capsules extend dorsal and palmar pouches (recessus dorsales et palmares) The palmar pouches are enforced by sesamoid cartilage.

Each joint has a medial and a lateral collateral ligament and elastic ligaments dorsally. The dog has two long elastic cord like ligaments (ligamenta dorsalia longa) extending from the second phalanx to the lateral aspect of the third phalanx. In the cat, in addition to the two long dorsal ligaments, there is a short single dorsal ligament (ligamentum dorsale breve), which extends from the side of the second phalanx to the extensor process of the third phalanx. This anatomical location allows the flexion of the distal interphalangeal joint and therefore the protrusion of the claw by simultaneous contraction of the deep digital flexor tendon and relaxation of the elastic dorsal ligaments.

Unlike the dog, the cat can fully retract its claws into the fur of the paw. While the claws are contracted the claw is under maximal dorsal flexion and in contact with the corresponding metacarpal bone.

Interdigital ligaments

Annular ligaments (ligamenta anularia palmaria) brace the superficial and deep digital flexor tendons at the level of the proximal sesamoid bones of the metacarpophalangeal joints of the second to fifth digit. These palmar annular ligaments furnish insertion to the deep interdigital ligaments, which hold the digits together and support the carpal and digital pads.

A superficial interdigital ligament runs transversely from the palmar surface of the distal end of the second metacarpal bone to the same location on the fifth metacarpal bone.

Phalangeal joints of the ruminants

Metacarpophalangeal joints or fetlock joints

The two metacarpophalangeal joints are **hinge joints** formed by the trochlea, which consists of the separate distal ends of the third and fourth metacarpal bones, the articular surface of the first phalanx and two proximal sesamoid bones on the palmar aspect (Fig. 3-46). Each joint has its own joint capsule with a dorsal and a palmar pouch each (recessus dorsales et palmares).

The **dorsal pouch** (recessus dorsalis) extends proximally between the metacarpal bones and the tendons of the common and lateral digital extensor muscles. The dorsal joint capsules are thickened by fibrocartilage. The tendons are each surrounded by a synovial sheath and subtendinous bursae, which facilitates their passage over the dorsal joint pouch.

The **palmar pouch** (recessus palmaris) extends proximally between the metacarpal bones, the interosseous muscle and the deep and superficial digital flexor tendons. The flexor tendons share a common synovial sheath at this level.

The axial part of the joint capsules are fused. Their palmar pouches communicate with each other proximal to the interdigital branch of the interosseous muscle.

Injection site
Both fetlock joints can be reached with one injection. The needle is inserted into the dorsal pouch at the border of the lateral or medial extensor tendon and advanced horizontally.

Ligaments of the fetlock joint (Fig. 3-48 and 3-49) can be divided into:

- **proximal interdigital ligament** (ligamentum interdigitale proximale) joins the proximal phalanges of the weightbearing digits to their axial sesamoid bones,
- **axial** and **abaxial collateral ligaments** bridge each fetlock joint and
- **proximal, middle** and **distal sesamoidean ligaments.**

The tendinous **middle interosseous muscle** (m. interosseus medius) or suspensory ligament supports the fetlock proximally. It originates from the distal carpal bones, extends distally on the palmar surface of the metacarpal bones and divides into four branches at the distal third of the metacarpus. The four branches are divided into:

Fig. 3-46. Radiograph of the foot of an ox (dorsopalmar projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

- **Middle part,** which subdivides further into two branches for the axial proximal sesamoid bones and one interdigital branch for each digit, the interdigital branch for the third digit joins the medial tendon of the common digital extensor tendon and the interdigital branch to the fourth digit the lateral digital extensor tendon,
- **Lateral and medial branch,** which insert with a deep branch on the abaxial proximal sesamoid bones and extend a superficial branch to the extensor tendons and
- **Strong branch,** which subdivides into a medial and a lateral branch, both branches unite more distally with the superficial digital flexor tendon, thus forming a sheath around the deep digital flexor tendon.

The **middle ligaments of the fetlock** (Fig. 3-48 and 49) comprise:

- **Medial** and **lateral palmar ligaments** (ligamenta palmaria mediale et laterale) which join the proximal sesamoid bones of the third digit to the ones of the fourth digit.
- **Interdigital intersesamoid ligament** between the two axial sesamoid bones.
- **Collateral sesamoid ligaments** (ligamenta sesamoidea collateralia), which connect the abaxial proximal sesamoids with the first phalanx.

The distal support of the fetlock is provided by (Fig. 3-49):

- **Cruciate sesamoid ligaments** (ligamenta sesamoidea cruciata), which extend from the base of each proximal sesamoid to the lateral aspect of the corresponding first phalanx.
- **Interdigital phalangosesamoidean ligaments** (ligamenta phalangosesamoidea interdigitales), which connect the axial proximal sesamoids with the proximal end of the opposite first phalanx.
- **Oblique sesamoid ligaments** (ligamenta sesamoidea obliqua), which connect the abaxial proximal sesamoids to the first phalanx.

Proximal interphalangeal joints or pastern joints

The pastern joints are **saddle joints,** formed by the distal trochlea of the first phalanx and the proximal articular surface of the second phalanx. The two joints have separate capsules. Each forms dorsal and palmar pouches (recessus dorsales et palmares).

The **dorsal pouch** (recessus dorsalis) is indented by the extensor tendons and extends distally and proximally on the axial and abaxial aspect.

The **palmar pouch** (recessus palmaris) is smaller and covered by the flexor tendons.

Each joint is supported by axial and abaxial collateral ligaments (ligamenta collateralia). An additional axial ligament

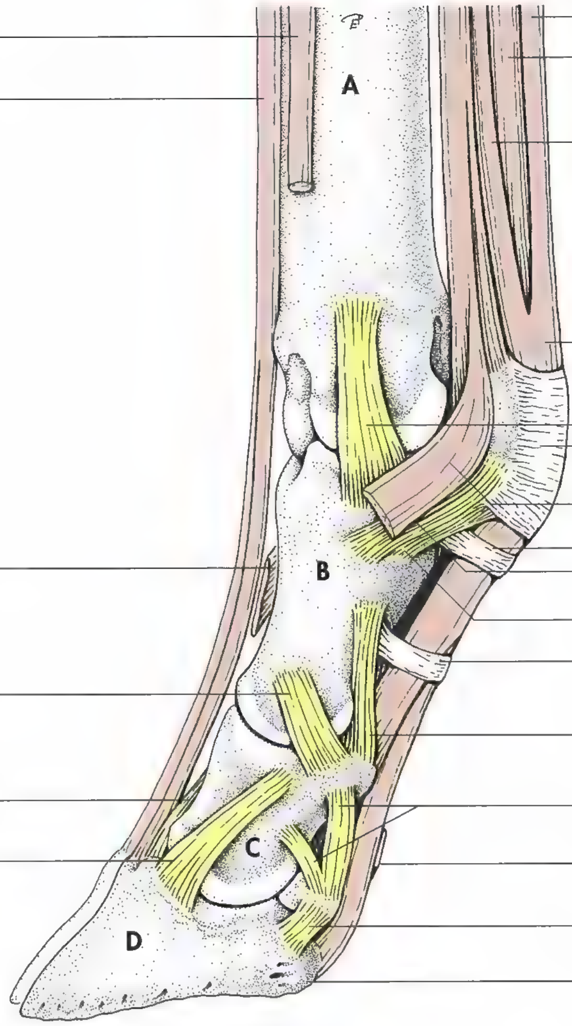

Fig. 3-47. Ligaments and tendons of the left lateral front foot of the ox, lateral aspect (schematic, **A** metacarpus, **B** first phalanx, **C** second phalanx, **D** third phalanx).

bridges both the pastern and the coffin joint dorsally. Three **palmar ligaments,** a central, an axial and an abaxial palmar ligament provide further support to each pastern joint (Fig. 3-49).

Additional bands arise from the digital fascia and insert on to the first phalanges. These support the flexor tendons on the palmar aspect (Fig. 3-47, 3-48, 3-49):

- Palmar annular ligament (ligamentum anulare palmare),
- Proximal and distal annular digital ligament (ligamentum anulare digiti) and
- Distal interdigital ligament (ligamentum interdigitale distale).

Distal interphalangeal joints or coffin joints

The **coffin joints** are **saddle joints** formed by the distal trochlea of the second phalanges, the articular surfaces of the third phalanges and the distal sesamoid or navicular bone on the palmar aspect.

The joint capsules are completely separated and have dorsal and palmar pouches (recessus dorsales et palmares):

- **Dorsal pouches** (recessus dorsales) reach about 1 cm beyond the coronet under the extensor tendons.
- **Palmar pouches** (recessus palmares) extend proximally up to the middle of the second phalanges and are covered by the deep digital flexor tendons.

Each joint is supported by the following ligaments (Fig. 3-47 and 3-49):

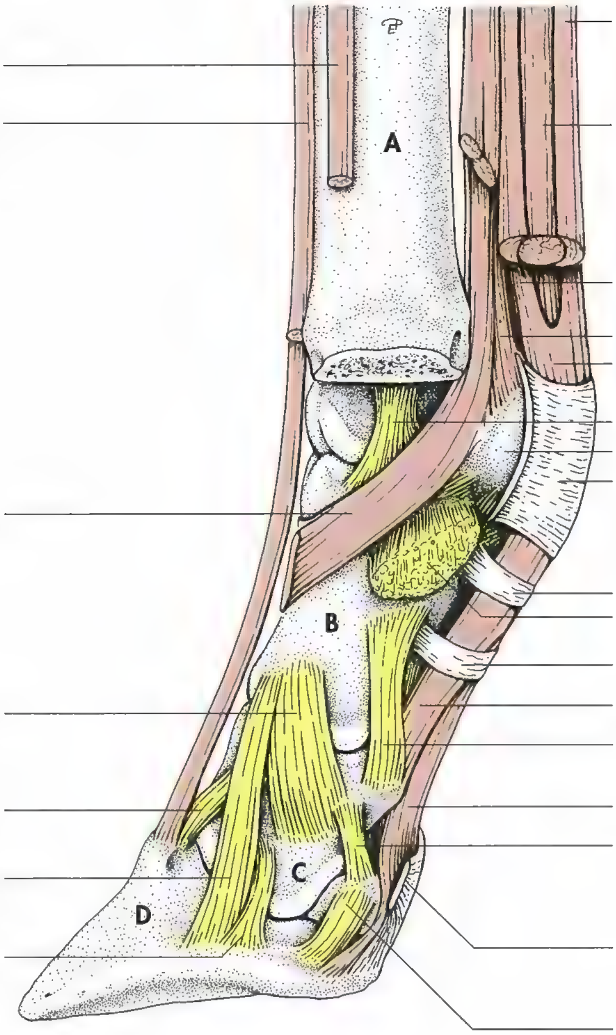

Fig. 3-48. Ligaments and tendons of the left medial front foot of the ox, axial aspect (schematic, **A** metacarpus, **B** first phalanx, **C** second phalanx, **D** third phalanx) (Ellenberger and Baum, 1943).

- **Distal interdigital ligaments** (ligamentum interdigitale distale), which are two cruciate ligaments between the main digits.
- **Dorsal ligament of the coffin joints** (ligamentum dorsale), which is an elastic band extending from the distal end of the second phalanx axially to the extensor process of the third phalanx.
- **Axial** and **abaxial collateral ligaments** (ligamenta collateralia).
- **Ligaments of the distal sesamoid bone,** which can be divided into elastic axial and abaxial ligaments connecting the distal sesamoid to the second phalanx and collateral ligaments connecting the sesamoid to the third phalanx.

Support of the dewclaws

The second and fifth digit are joined to the cannon bone proximally and to the main digits distally by fasciae, which form distal, proximal and transverse bands.

Phalangeal joints of the horse

Metacarpophalangeal joint or fetlock joint

The fetlock joint is a composite joint formed by the trochlea of the cannon bone, the proximal articular surface of the first phalanx and the proximal sesamoid bones (Fig. 3-50 and 51). It acts as a hinge joint with the major movements being flexion and extension allowing only limited lateral movement. In

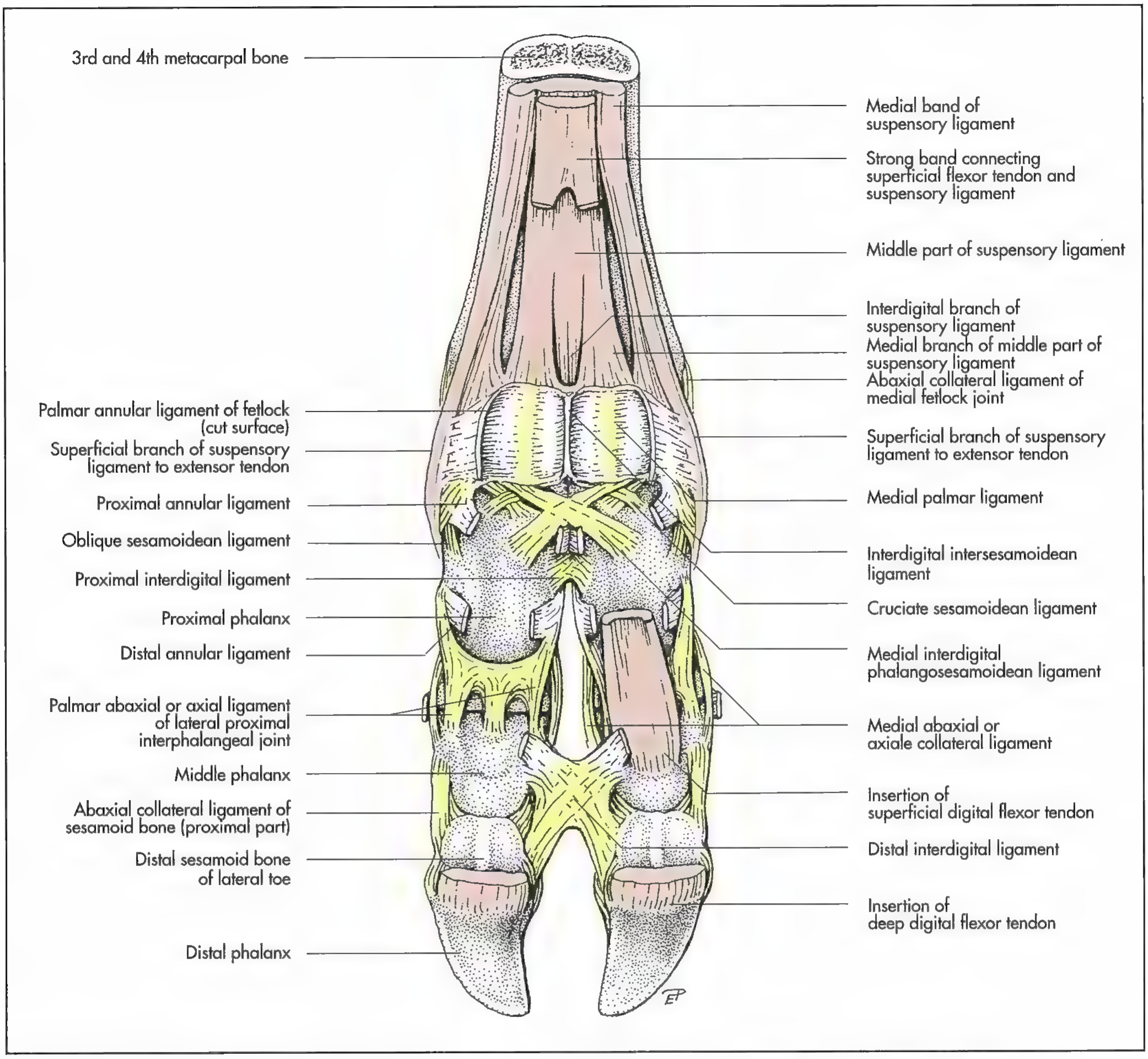

Fig. 3-49. Ligaments and tendons of the left front foot of the ox (schematic, palmar aspect) (Ellenberger and Baum, 1943).

the standing position the joint is in partial flexion. The joint capsule has a dorsal and a palmar pouch:

- **Dorsal pouch** (recessus dorsalis) extends about 2 cm proximally between the cannon bone and the extensor tendon, a bursa is interposed between the joint capsule and the extensor tendon and
- **Palmar pouch** (recessus palmaris) lies between the cannon bone and the suspensory ligament (m. interosseus medius). It extends 4–5 cm proximally.

The ligamentous support of the fetlock consists of:

- **Collateral ligaments** (ligamenta collateralia) arise from each side of the distal end of the cannon bone and insert on the eminences on each side of the proximal end of the first phalanx and
- **proximal, middle** and **distal ligaments** of the proximal sesamoid bones.

The tendinous interosseous muscle or suspensory ligament provides the **proximal support for the proximal sesamoid bones.** It is attached proximally to the distal row of the carpal bones and to the proximal part of the cannon bone. It passes between the lateral and medial splint bone in the metacarpal groove on the palmar surface of the cannon bone. Above the fetlock it divides into two diverging branches, which insert on the proximal sesamoid bones. The **metacarpointersesamoidean ligament** (ligamentum metacarpointersesamoideum) extends between the distal end of the metacarpus and the palmar ligament. It provides additional support to the fetlock on the palmar aspect. The **middle ligaments of the proximal sesamoids** comprise:

Fig. 3-50. Sagittal section of the digit of a horse.

Fig. 3-51. Radiograph of the digit of a horse (lateromedial projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

- **Palmar ligament** (ligamentum palmare): A broad fibrocartilagenous ligament, which unites the two proximal sesamoids and enables, together with the sesamoid bones the frictionless movement of the flexor tendons over the fetlock joint (scutum proximale).
- **Medial** and **lateral collateral ligaments** (ligamenta collateralia), which connect the proximal sesamoids to the metacarpal bone proximally and to the first phalanx distally.

There are several **distal sesamoid ligaments:**

- **Straight sesamoidean ligament** (ligamentum sesamoideum rectum): originates proximal to the base of the sesamoid bones and inserts with two branches, a strong branch on the second phalanx and a weaker branch on the first phalanx.
- **Oblique sesamoidean ligaments** (ligamenta sesamoidea obliqua) accompany the straight one on each side and insert on the palmar surface of the first phalanx.
- **Cruciate sesamoidean ligaments** (ligamenta sesamoidea cruciata) run deep to the other distal sesamoidean ligaments, they arise on the base of the sesamoid bones, cross each other and insert on the opposite side of the first phalanx.
- **Short sesamoidean ligaments** (ligamenta sesamoidea brevia) extend from the base of the sesamoids to the palmar margin of the first phalanx.
- **Suspensory ligament** extends a medial and a lateral branch dorsally and distally, where they join the common digital extensor tendon. These branches give additional support to the sesamoids. The suspensory ligament, the palmar ligament and the straight and oblique sesamoidean ligaments, together with the sesamoids themselves, form the **stay apparatus,** which supports the fetlock.

Injection sites:

- The fetlock joint is injected in the weightbearing horse into the dorsoproximal pouch of the joint. The joint space is palpated and a 2 cm needle inserted medial to the common extensor tendon and directed distomedially.

Proximal interphalangeal joint or pastern joint

The **pastern joint** is formed by the junction of the trochlea of the first phalanx and the proximal end of the second phalanx. It is a **saddle joint,** with a limited range of movement.

The **joint capsule** blends with the common digital extensor tendon dorsally, the collateral ligaments on the lateral and medial side and the straight sesamoidean ligament palmarly. A small dorsal recess pouches proximally. There are two collateral and several palmar ligaments:

- **Collateral ligaments** (ligamenta collateralia) extend between the first and second phalanx and

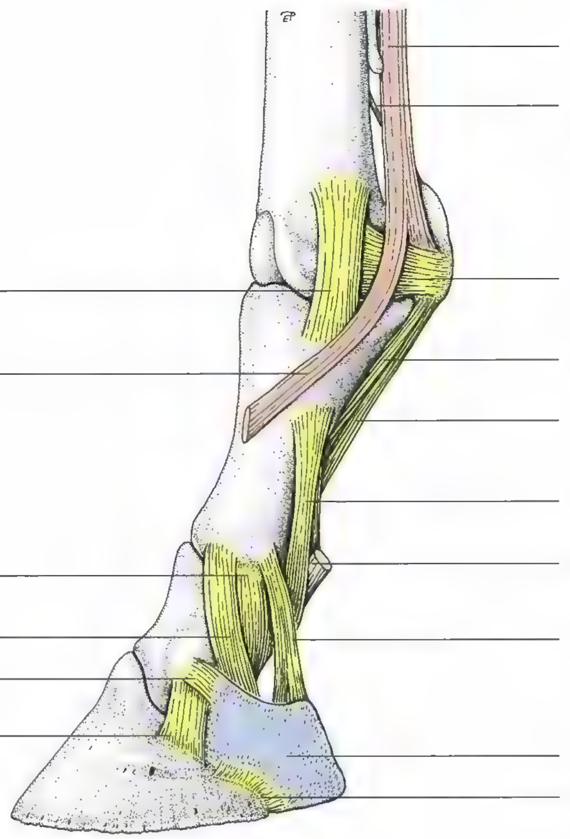

Fig. 3-52. Phalangeal joints of the left digit of the horse (schematic, lateral aspect) (Ghetie, 1954).

- **palmar ligaments** (ligamenta palmaria) consist of a central pair, the axial and abaxial ligaments, which run parallel to the straight sesamoidean ligament and the lateral and medial palmar ligaments.

They form, together with the straight sesamoidean ligament and the second phalanx the medial scutum over which the deep digital flexor tendon runs. Additional **lateral palmar ligaments** extend between the second and third phalanx.

Distal interphalangeal joint or coffin joint

The **coffin joint** is a **composite joint** formed by the distal trochlea of the second phalanx, the third phalanx and the **distal sesamoid bone (navicular bone).** It is a saddle joint with the chief movements being flexion and extension and a very limited range of lateral and rotational movements.

The joint capsule extends a small dorsal and a more spacious palmar pouch (Fig 3-56, 57 and 60):

- **Dorsal pouch** (recessus dorsalis) extends under the common extensor tendon about 1 cm proximal to the coronet and
- **palmar pouch** (recessus palmaris) extends under the deep digital flexor tendon up to the middle of the second phalanx.

The palmar aspect of the navicular bone is covered by a layer of cartilage (scutum distale), which facilitates passage of the deep digital flexor tendon over the navicular bone.

A **synovial bursa** (podotrochlear bursa, bursa podotrochlearis) is interposed between the navicular bone and the deep digital flexor tendon (Fig. 3-58 and 59).

The **ligaments of the coffin joint** can be divided into:

- **Medial** and **lateral collateral ligaments** (ligamenta collateralia) between the second and third phalanx, they blend with the lateral and medial part of the joint capsule and send fibres to the cartilages and to the ligaments between the second phalanx and the cartilages.

The **ligaments of the distal sesamoid bone** can be divided into:

- **Impar distal sesamoidean ligament** (ligamentum sesamoideum distale impar) extends from the distal rim of the navicular bone to the palmar border of the articular surface of the coffin bone (Fig. 3-53) and

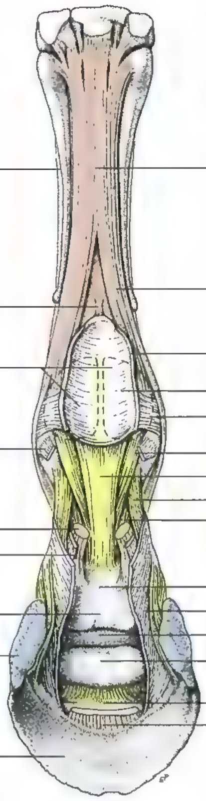

Fig. 3-53. Ligaments of the phalangeal joints of the horse (schematic, palmar aspect) (Ellenberger and Baum, 1943).

- **collateral sesamoidean ligaments** (ligamenta collateralia sesamoidea) are elastic bands, which are attached proximal to the depressions on each side of the distal end of the first phalanx and are directed palmarodistally, they insert on the coffin bone, the cartilages and the navicular bone.

Ligaments of the cartilages of the distal phalanx

- **Chondroungulocompedal ligaments** (ligamenta chondroungulocompedalia) extend between the distal end of the first phalanx and the proximopalmar aspect of the coffin bone and the cartilages.
- **Lateral** and **medial chondrocoronal ligaments** (ligamenta chondrocoronalia medialis et lateralis) connect the dorsal extremity of the cartilages to the second phalanx and the collateral ligaments of the coffin joint.
- **Lateral** and **medial chondroungular collateral ligaments** (ligamenta chondroungularia collaterale mediale et laterale) between the distal part of the cartilage and the angle of the distal phalanx.
- **Lateral** and **medial chondrosesamoidean ligaments** (ligamenta chondrosesamoidea mediale et laterale) between the cartilages and the corresponding side of the navicular bone.
- **Cruciate chondroungular ligaments** (ligamenta chondroungularia cruciuata) between the axial aspect of the cartilages to the palmar end of the opposite angle of the distal phalanx.
- **Chondropulvinal ligament** (ligamentum chondropulvinale) consists of fibres between the axial aspect of the cartilages and the digital cushion (Fig. 3-52 and 53).

Injection site:

- **Coffin joint:** the injection is performed in the weight-bearing horse with a 2 cm needle. The needle is inserted into the dorsoproximal pouch 1 cm proximal to the coronary band and 1 cm medial or lateral to the midline. The needle is directed distal and toward midline.

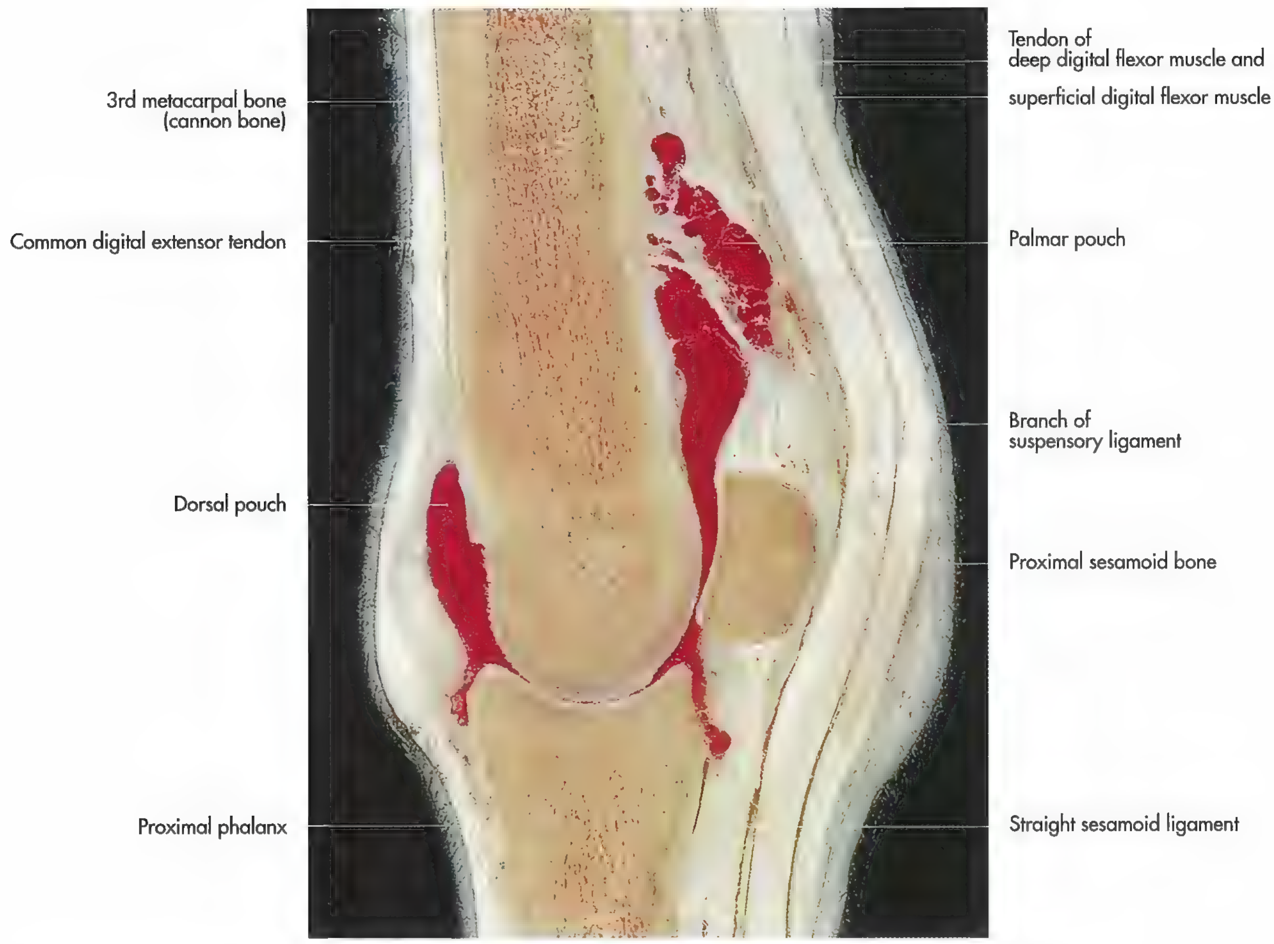

Fig. 3-54. Acrylic cast of the fetlock joint of a horse (paramedian section) (courtesy of Dr. Astrid Stiglhuber, Vienna).

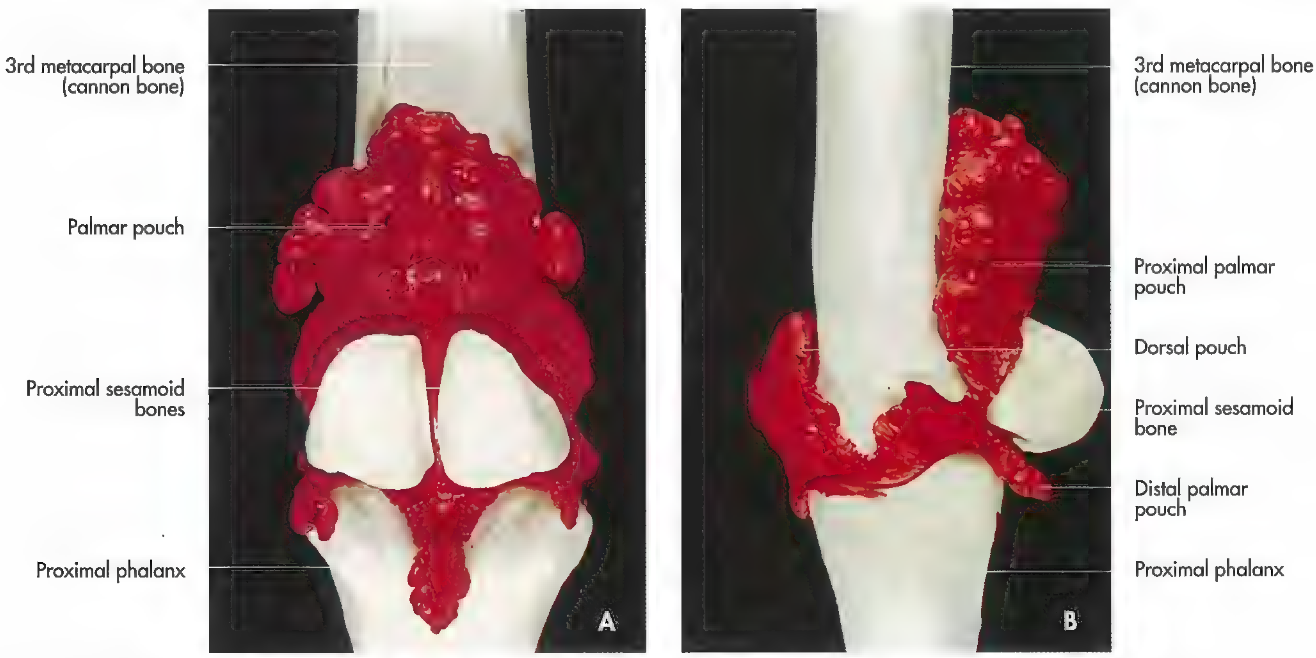

Fig. 3-55. Acrylic cast of the fetlock joint of a horse (**A** palmar and **B** lateral aspect) (courtesy of Dr. Astrid Stiglhuber, Vienna).

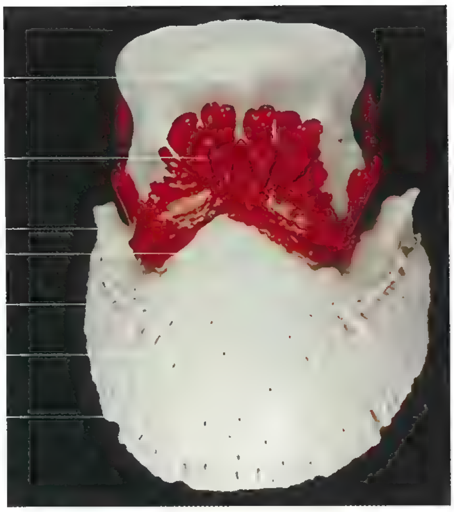

Fig. 3-56 Acrylic cast of the coffin joint of a horse (dorsal aspect) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Fig. 3-57 Acrylic cast of the coffin joint of a horse (palmar aspect) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Fig. 3-58. Acrylic cast of the coffin joint (red) and the navicular bursa (blue) of a horse (lateral aspect) (courtesy of Prof. Dr. Sabine Breit, Vienna).

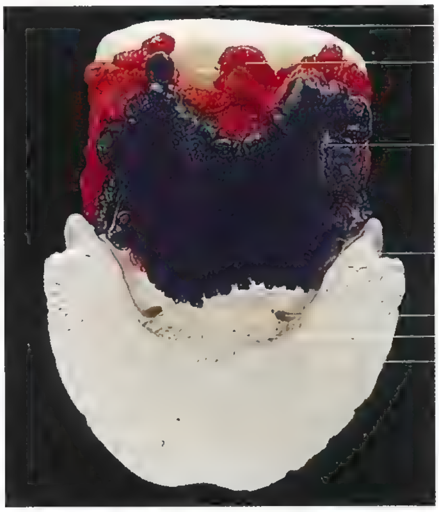

Fig. 3-59. Acrylic cast of the coffin joint (red) and the navicular bursa (blue) of a horse (palmar aspect) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Muscles of the thoracic limb (musculi membri thoracici)

The reduction of the rays of the limb and the functional specialisation of the locomotor system in the different species are reflected in the musculature. Parts of the body, which are essential for fast forward movement are heavily muscled, such as the gluteal area, whereas other regions of the limbs, which are submitted to stress and strain, are strengthened by tendinous structures.

The muscles of the thoracic limb comprise the **girdle** or **extrinsic musculature,** between the forelimb and the trunk and the **intrinsic musculature of the limb,** which bridges one or more joints of the same limb (Fig. 3-61 to 64).

The strong girdle muscles join the limb to the trunk **(synsarcosis)** without forming a conventional articular joint. They form a dynamic sling, which suspends the body between the forelimbs in the standing animal and controls the swing of the limb during progression.

Deep fasciae of the thoracic limb

As in other parts of the body the musculature of the forelimb is supported by fasciae. The **deep fascia of the neck** (fascia cervicalis profunda) and the **deep fascia of the trunk** (fascia trunci profunda) extend onto the leg to form the deep fasciae of the thoracic limb. The fasciae ensheath the muscles of the thoracic limbs and are named after their position.

Fig. 3-60. Acrylic cast of the coffin joint (red) and the navicular bursa (blue) of a horse (paramedian section) (courtesy of Prof. Dr. Sabine Breit, Vienna).

The deep fascia on the medial surface of the shoulder is called the **axillary fascia** (fascia axillaris). It runs over the medial musculature of the shoulder and under the broadest muscle of the back. It continues distally as the **brachial fascia** (fascia brachii) on the lateral surface of the brachium surrounding the deltoid, brachial, triceps and the biceps muscles. It extends intermuscular septa between those muscles and attaches to the scapula and the humerus.

The strong **antebrachial fascia** (fascia antebrachii) covers the extensor and flexor muscles of the elbow and digit in the forearm region. It is firmly fused to the periostium of the humerus and the olecranon and also to the collateral ligaments of the elbow joint and the accessory ligament of the deep digital flexor tendon. At the level of the carpus it becomes the fascia of the manus, which is divisible into a dorsal and palmar part.

The **dorsal deep fascia** (fascia dorsalis manus) contributes to the extensor retinaculum, which supports the extensor tendons. The **palmar deep fascia** (fascia palmaris manus) does the same for the flexor retinaculum, which bridges the flexor tendons on the palmar aspect of the carpus. In the horse the palmar deep fascia forms the annular ligament of the fetlock and other supportive structures of the fetlock.

Girdle or extrinsic musculature of the thoracic limb

The muscles of the shoulder girdle originate on the neck, back and thoracic region and attach to the scapula or humerus. They lay superficial to the intrinsic muscles of the cranial trunk and can be divided into a **superficial** and a **deep layer.**

Superficial layer of the extrinsic musculature of the thoracic limb

The superficial layer of the girdle musculature joins the forelimb to the trunk and is responsible for coordinating the movements of the limb, trunk, head and neck (Fig. 3-61 to 64 and Table 3-5 and 6). The superficial layer consists of the following muscles:

- Trapezius muscle (m. trapezius),
- Sternocleidomastoid muscle (m. sternocleidomastoideus),
  - Sternocephalic muscle (m. sternocephalicus),
  - Brachiocephalic muscle (m. brachiocephalicus),
- Omotransverse muscle (m. omotransversarius),
- Broadest muscle of the back (m lastissimus dorsi) and
- Superficial pectoral muscle (m. pectoralis superficialis).

The **trapezius muscle** is a broad, thin triangular muscle. It lays superficially and consists of a **cervical** (pars cervicalis) and a **thoracic portion** (pars thoracica), divided by a tendinous band. The cervical portion arises on the mid-dorsal raphe of the neck and the thoracic portion on the supraspinous ligament and the dorsal spinous processes, extending from the third cervical vertebra to the ninth thoracic vertebra. Both portions end on the spine of the scapula, the thoracic part unites with the thoracolumbar fascia and the cervical part with the omotransverse muscle.

The **sternocleidomastoid muscle** can be divided into two parts, the **sternocephalic muscle,** which extends between the sternum and the head and the **brachiocephalic muscle** between the humerus and the head. The latter can be further subdivided into the distal **cleidobrachial muscle** between the vestigial clavicle and the humerus and the proximal **cleidocephalic**

Tab. 3-5. Brachiocephalic muscle, innervation by accessory nerve, cervical nerves and axillary nerve.

Species	Name and Origin	Insertion	Action
Horse	**Cleidomastoid muscle** Mastoid process of the temporal bone and nuchal crest	On the deltoid tuberosity, humeral crest, shoulder fascia as **Cleidobrachialis muscle**	Draws neck and head down and backwards, when acting bilaterally and when the shoulder is fixed, draws head, upper arm fascia and neck to one side
Ox	**Cleidooccipital muscle** Occipital bone Nuchal ligament	On the humeral crest as **cleidobrachialis muscle**	see above
	Cleidomastoid muscle Mastoid process Mandible		see above
Dog	**Cleidocervical muscle** Median line of nuchal ligament and occipital bone	Clavicular intersection as **cleidobrachialis muscle**	see above
	Cleidomastoid muscle Mastoid process of temporal bone		see above

muscle between the clavicular intersection and the head. The attachment of the separate parts of this muscle vary among species and the different units are named accordingly.

In carnivores the sternocephalic muscle has two portions, the **sternomastoid** and the **sternooccipital muscle** (m. sternomastoideus and m. sternooccipitalis). Both arise from the manubrium of the sternum together with the like-named muscles of the contralateral limb and insert on the mastoid process of the temporal bone and the nuchal crest of the occipital bone respectively.

In the ox the sternocephalic muscle has also two parts, the **sternomastoid** and the **sternomandibular muscle** (m. sternomastoideus and m. sternomandibularis). The sternomastoid muscle shows the same attachment as in carnivores. The sternomandibular muscle arises from the manubrium of the sternum and the first rib, extends cranially ventral to the jugular groove and attaches to the mandible by means of an aponeurosis.

In the pig the sternocephalic muscle is a single muscle named **sternooccipital muscle** (m. sternooccipitalis) and is similar to the same muscle in carnivores.

In the horse, the **sternomandibular muscle** (m. sternomandibularis) originates from the manubrium of the sternum, borders the trachea and the jugular groove ventrally and laterally and inserts with a thin tendon to the mandible.

The proximal portion of the **brachiocephalic muscle,** the **cleidocephalic muscle** passes from the clavicular intersection to several attachments on the head and neck. The **cleidomastoid muscle** exists in all domestic mammals, carnivores

Tab. 3-6. Sternocephalic muscle, innervation by ventral branch of accessory nerve.

Species	Name	Origin	Insertion	Action
Horse	**Sternomandibular muscle**	Manubrium	Neck facing border of the mandible	Flexor of head and neck when acting bilaterally, draws head and neck to the side, when acting unilaterally, fixes the head during swallowing
Ox	**Sternomandibular muscle**	Manubrium and 1st rib	Rostral border of the masseter muscle, Buccal fascia	see above
	Sternomastoid muscle	Manubrium	Temporal bone	see above
Dog	**Sternooccipital muscle**	Manubrium	Nuchal crest	see above
	Sternomastoid muscle	Manubrium	Mastoid process	see above

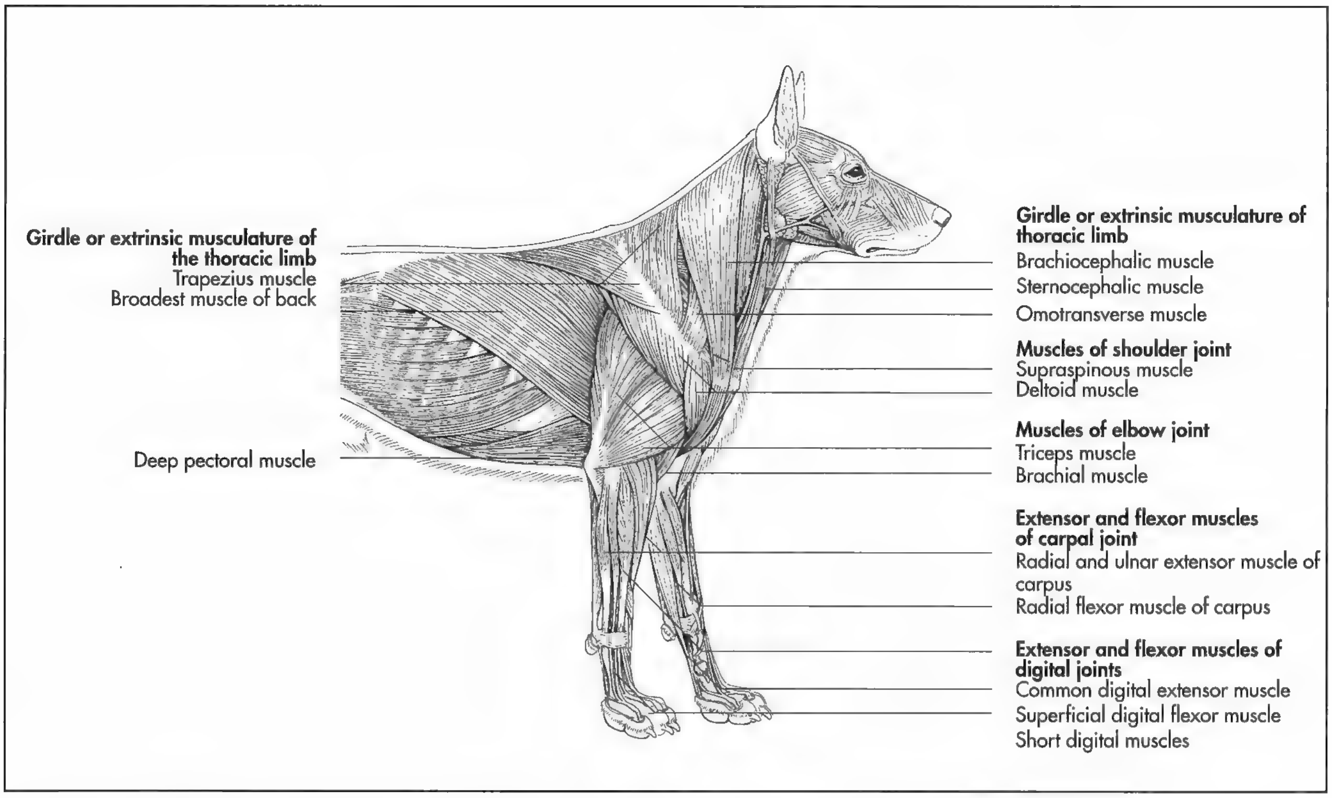

Fig. 3-61. Superficial layers of the extrinsic and intrinsic musculature of the thoracic limb of the dog (schematic).

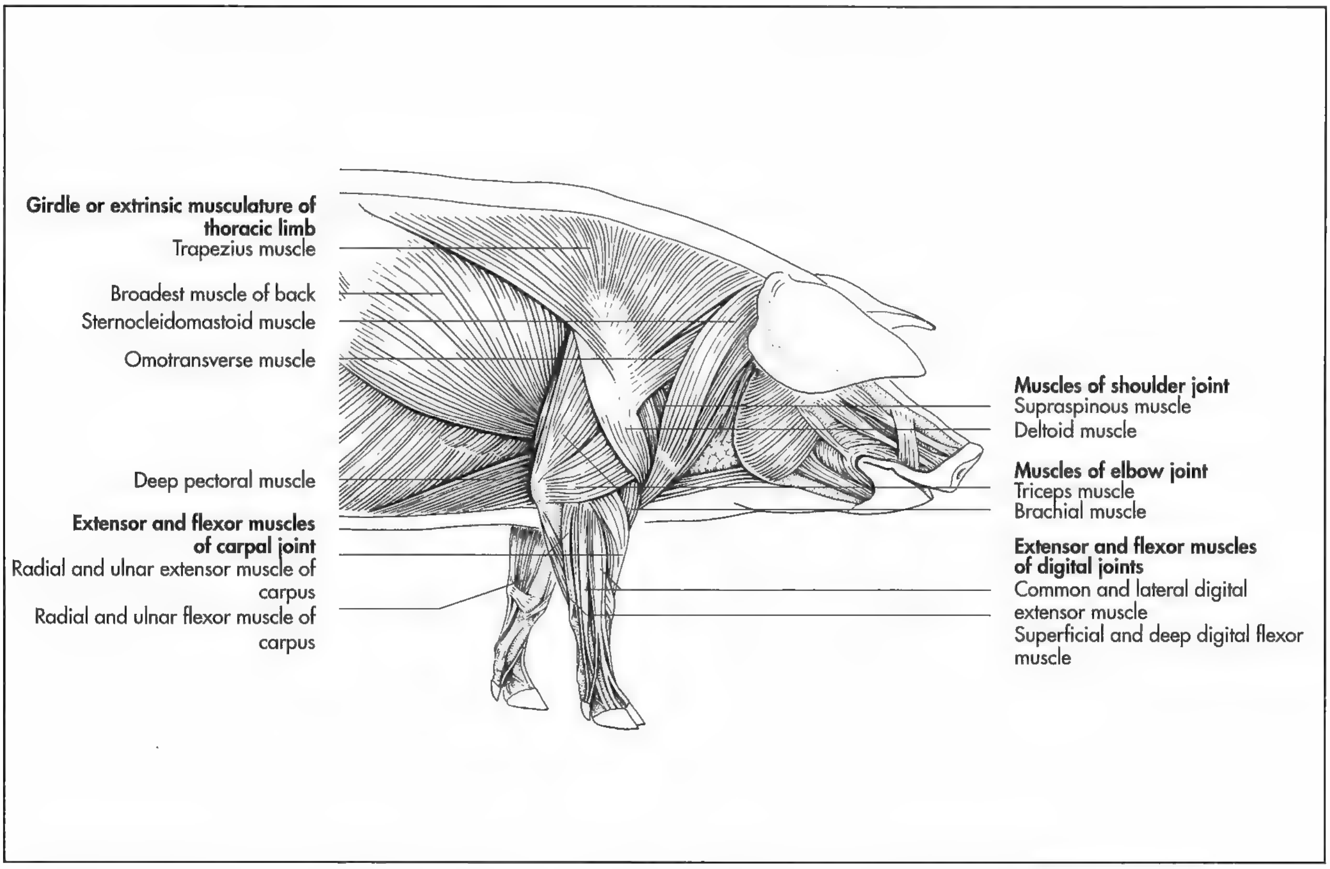

Fig. 3-62. Superficial layers of the extrinsic and intrinsic musculature of the thoracic limb of the pig (schematic).

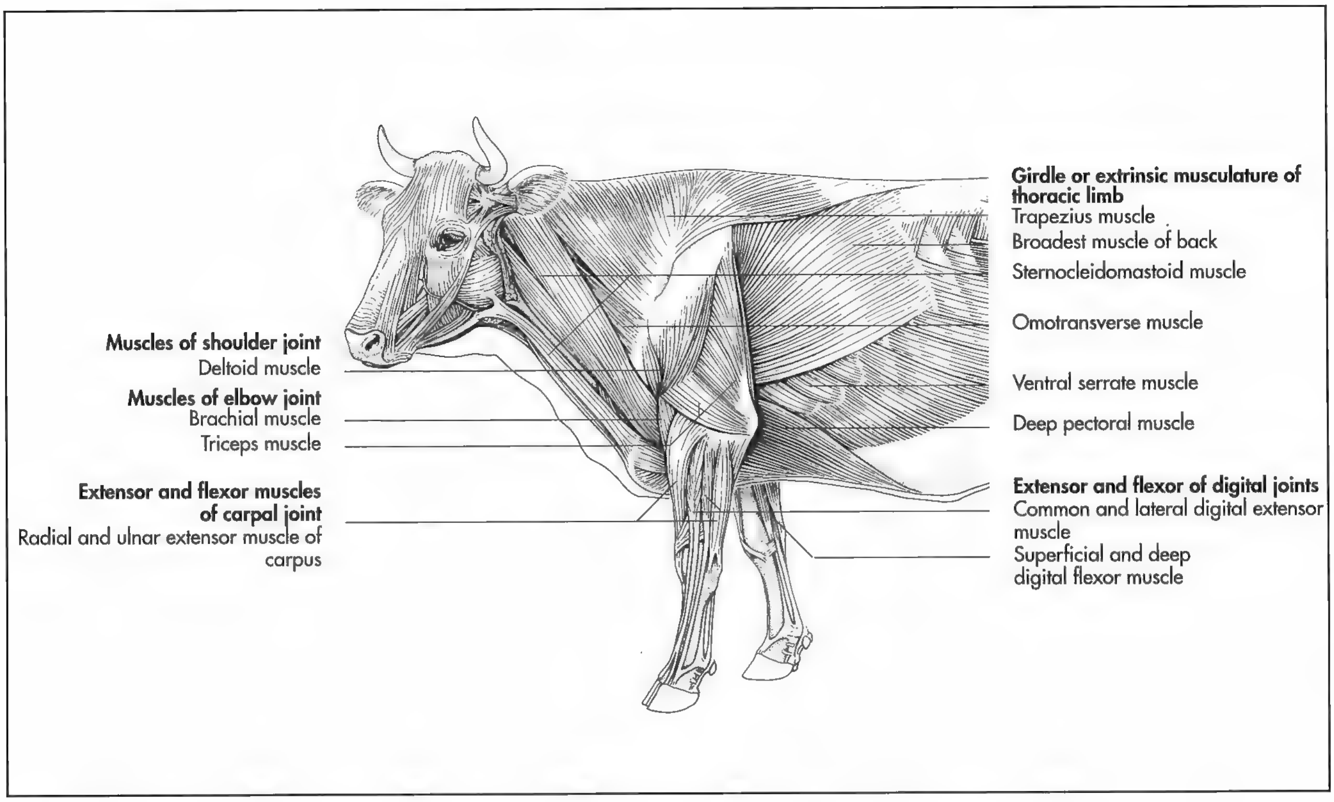

Fig. 3-63. Superficial layers of the extrinsic and intrinsic musculature of the thoracic limb of the ox (schematic).

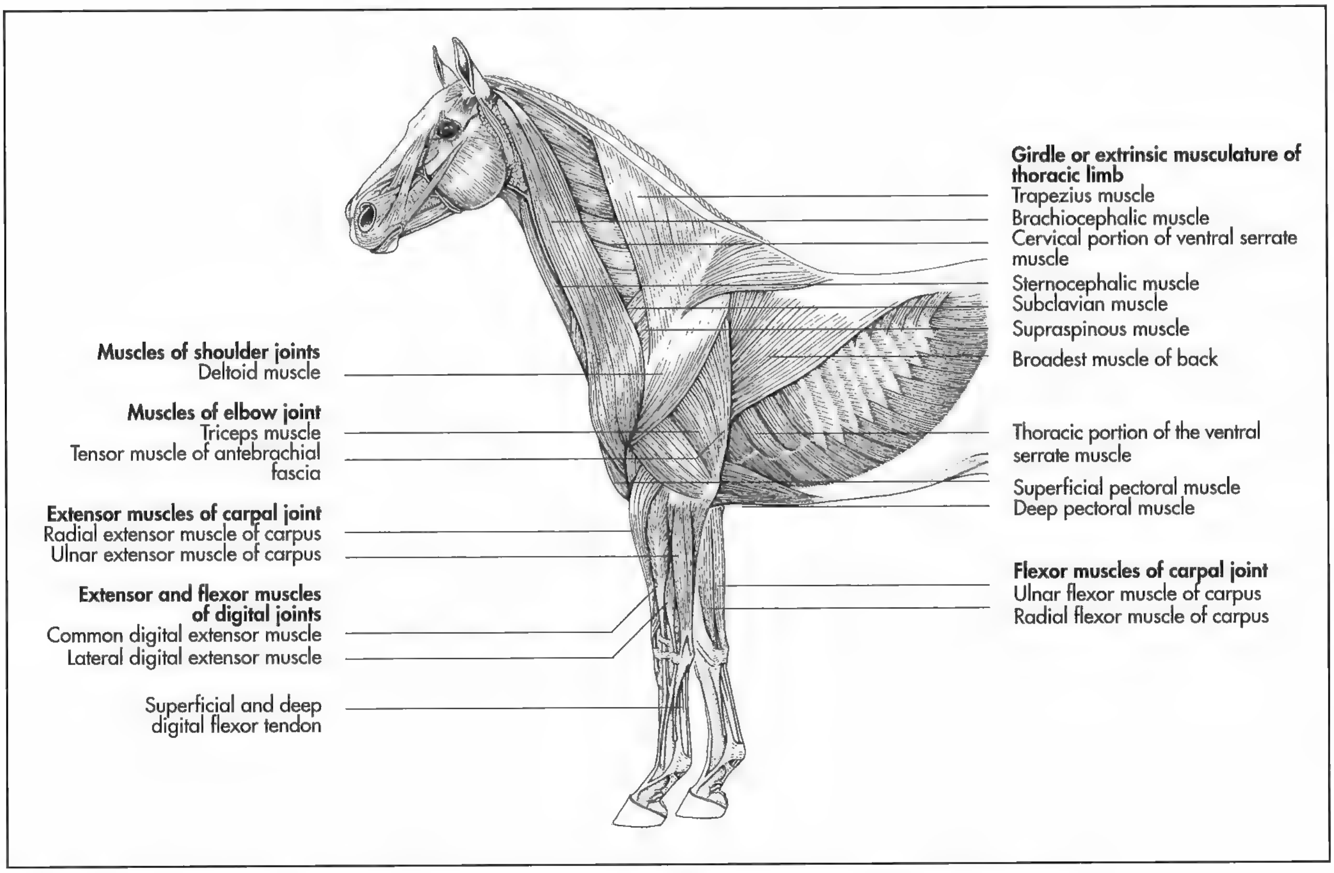

Fig. 3-64. Superficial layers of the extrinsic and intrinsic musculature of the thoracic limb of the horse (schematic).

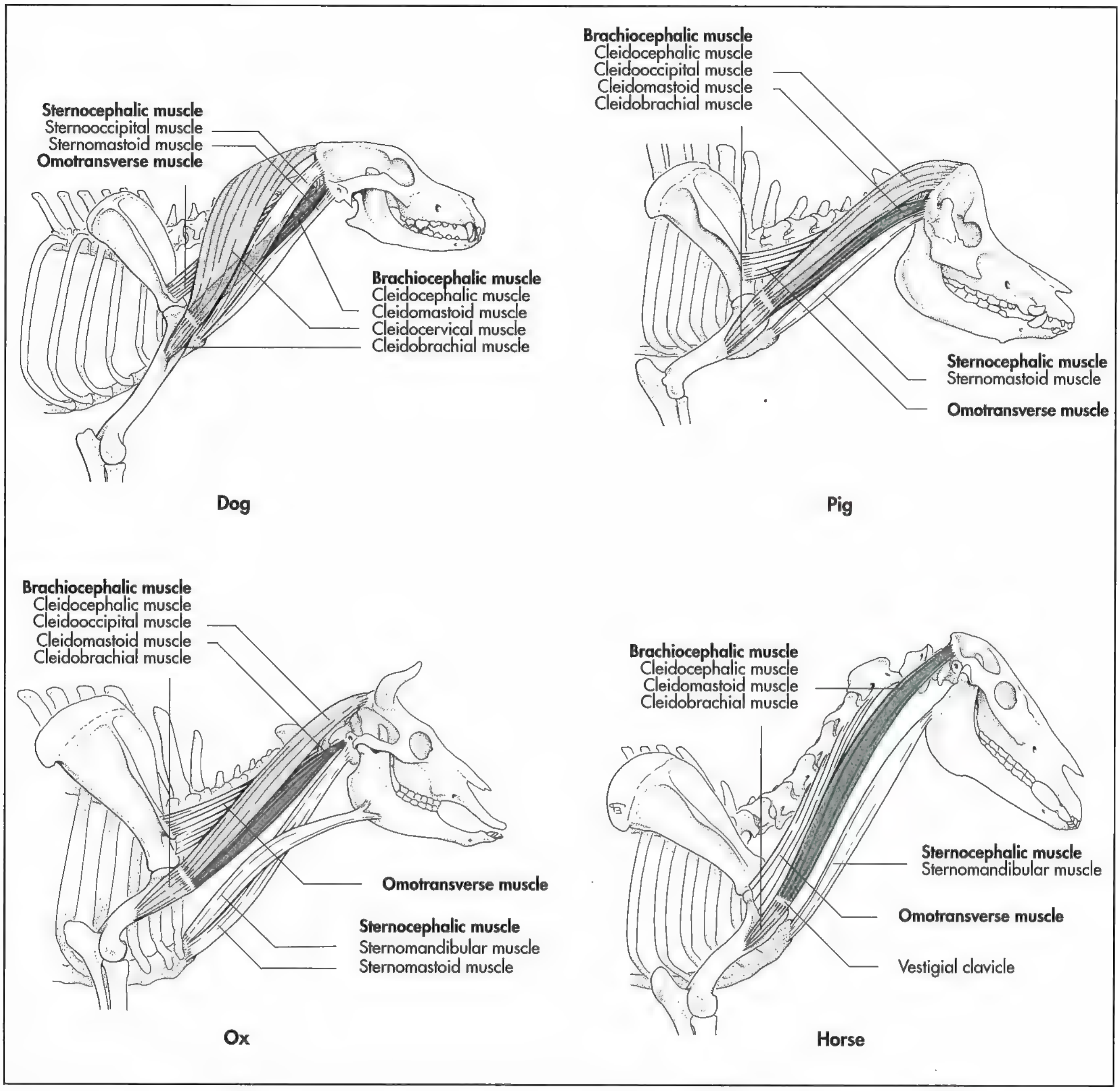

Fig. 3-65. Sternocleidomastoid muscle of the domestic mammals (schematic) (Ellenberger and Baum, 1943).

show an additional **cleidocervical muscle** (m. cleidocervicalis) and ruminants and the pig a **cleidooccipital muscle** (m. cleidooccipitalis).

The **cleidocervical muscle** is a superficial muscle, which originates from the midline of the neck and unites with the cleidobrachial muscle (Fig. 3-76). The **cleidomastoid muscle** of the horse extends between the temporal bone and unites also with the cleidobrachial muscle. It is fused to the splenius and long muscle of the head and omotransverse muscles. It forms the dorsal border of the jugular groove and covers the craniolateral aspect of the shoulder joint.

The **cleidobrachial muscle** (m. cleidobrachialis) extends between the vestigial clavicle and the humeral crest, bridging the shoulder joint.

The **omotransverse muscle** is a strong cord like muscle between the wing of the atlas, the transverse process of the axis and the fascia covering the lateral aspect of the shoulder joint and the spine of the scapula (Fig. 3-65). Its ventral border is fused to the cervical part of the trapezius muscle and in the horse it unites with the cleidomastoid muscle (Fig. 3-69).

The flat, extended **broadest muscle of the back** has a broad origin from the thoracolumbar fascia and lies caudal

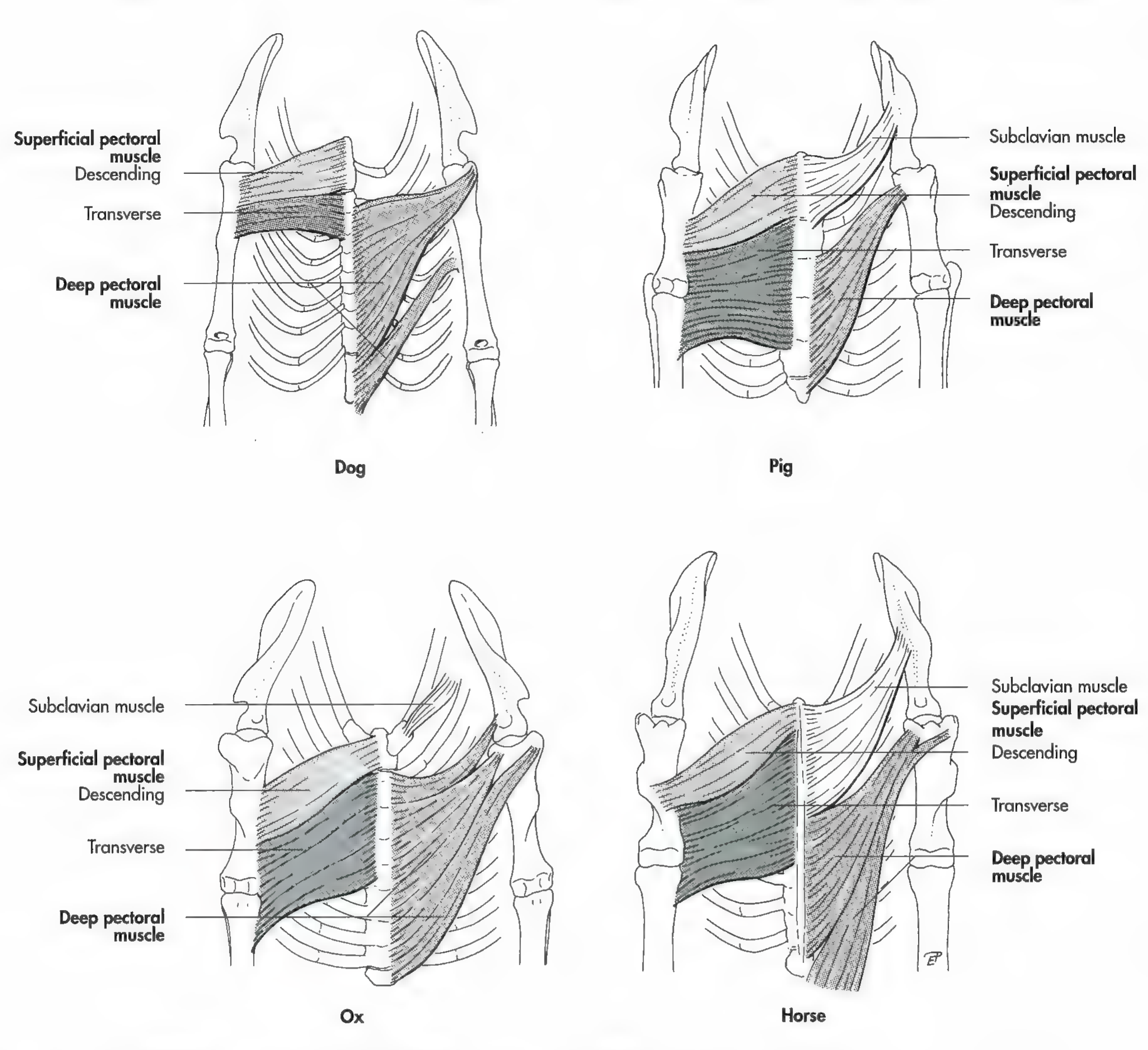

Fig. 3-66. Pectoral muscles of the domestic mammals (schematic) (Ellenberger and Baum, 1943).

to the scapula on the lateral aspect of the thorax and trunk (Fig. 3-61 to 64). Its fibres are orientated in a cranioventral direction and converge towards its insertion on the major and teres tubercle of the humerus.

In carnivores the broadest muscle of the back has additional attachments on the last thoracic vertebrae, the lumbar vertebrae and the ribs. Its cranioventral fibres pass under the triceps muscle of the forearm and end with an aponeurosis, which partly blends with the tendon of the teres major muscle to insert on the teres major tuberosity. Since it gives off a branch to the deep pectoral muscle it also attaches to the crest of the greater tubercle.

In the horse the broadest muscle of the back is a very strong muscle, which originates from the supraspinous ligament of the thoracic and lumbar vertebrae and from the thoracolumbar fascia. Its cranial border covers the caudal angle and the cartilage of the scapula. Its tendon inserts with the tensor muscle of the antibrachial fascia and the teres major muscle on the medial aspect of the proximal humerus.

The **superficial pectoral muscles** occupy the space between the ventral part of the thoracic wall and the proximal part of the thoracic limb, forming the ventral aspect of the axilla (Fig. 3-66 to 69). They comprise two muscles, the **descending** (m. pectoralis descendens) and **transverse pectoral muscle** (m. pectoralis transversus).

The **descending pectoral muscle** originates from the manubrium of the sternum and terminates on the crest of the greater tubercle of the humerus. The transverse muscle arises caudal to the descending pectoral muscle from the ventral aspect of the sternum and blends with the fascia of the forearm.

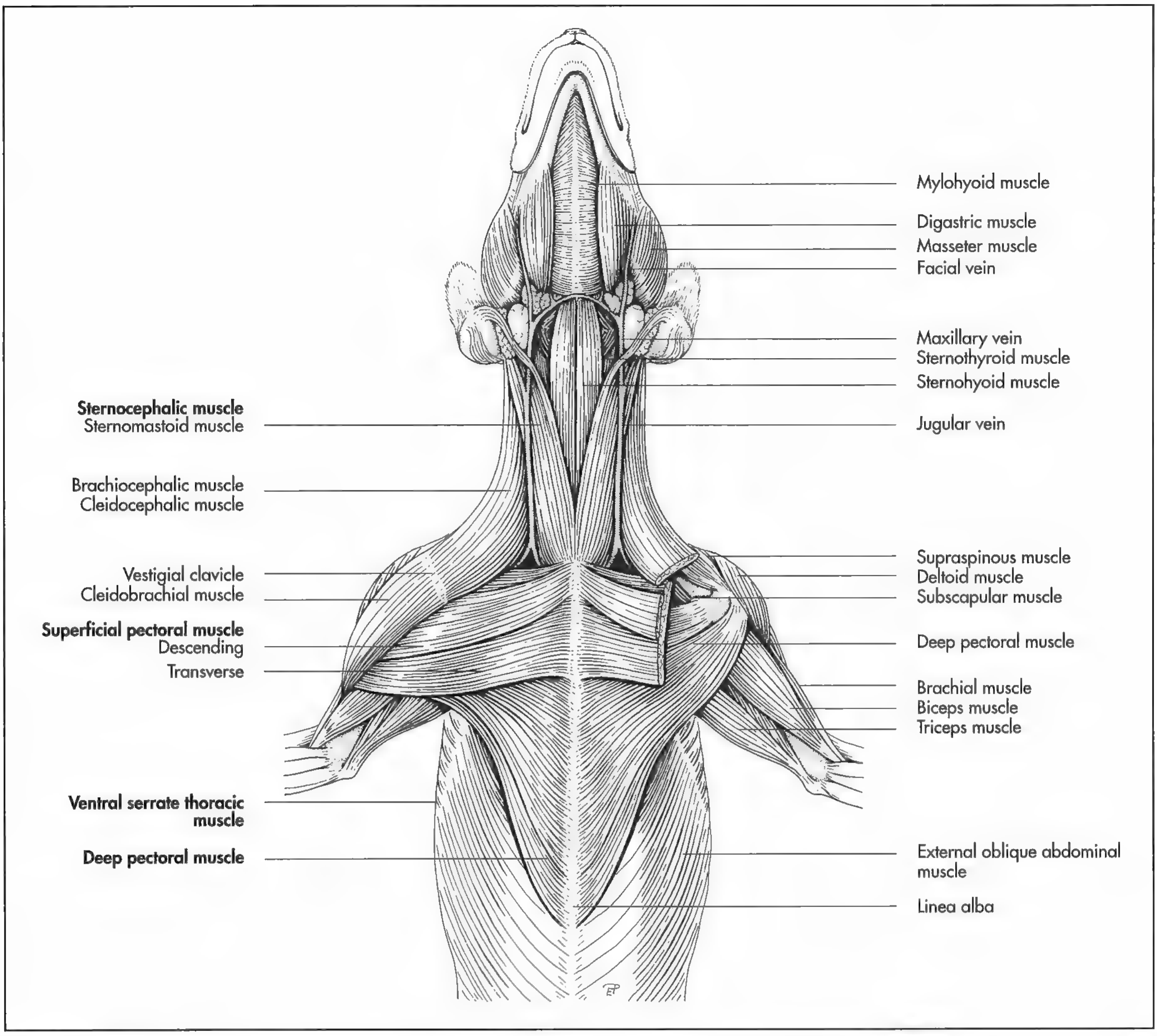

Fig. 3-67. Pectoral and ventral cervical muscles of the dog (schematic, ventral aspect) (Anderson and Anderson, 1994).

In carnivores the narrow, bandshaped descending pectoral muscle is hardly discernable from the thicker transverse pectoral muscle. Both cover the biceps muscle of the forearm and end together on the crest of the greater tubercle of the humerus.

In the horse the descending pectoral muscle forms a distinct prominence cranial to the sternum, which is visible under the skin in the living animal. It extends between the manubrium of the sternum and the humeral crest. The **transverse pectoral muscle** originates from the first six costal cartilages and the sternum and blends with the fascia of the forearm on the medial aspect of the elbow.

Deep layer of the extrinsic musculature of the thoracic limb

The deep layer of the girdle musculature of the thoracic limb provides the muscular suspension of the thorax between the limbs and plays a major role in the movement of the neck and limbs. It comprises:

- Deep pectoral muscle (m. pectoralis profundus),
- Subclavian muscle (m. subclavius),
- Rhomboid muscle (m. rhomboideus) and
- Ventral serrate muscle (m. serratus ventralis).

The **deep pectoral muscle** is a strong muscle, which originates from the sternum, the xiphoid cartliage and the costal cartilages and inserts on the medial or lateral aspect of the proximal humerus (Fig. 3-66) in the different species.

In carnivores, it can be divided into a major deep portion and a minor superficial portion. Both portions arise from the sternum and the deep fascia of the trunk. Its fibres run craniolaterally and terminate on the minor tubercle on the medial side of the humerus deep to the transverse pectoral muscle. A

Tab. 3-7. Girdle or extrinsic musculature of the thoracic limb.

Name Innervation	Origin	Insertion	Action
Superficial layer of shoulder musculature			
Trapezius muscle Dorsal branch of accessory nerve	Nuchal ligament Supraspinous ligament	Spine of scapula	Fixation of the shoulder; lifts, abducts and draws limb forward
Omotransverse muscle Accessory nerve	Wing of atlas or transverse process of 2nd cervical vertebra	Distal end of spine of scapula	Draws neck downward and sideward; draws scapula forward
Superficial pectoral muscle			
Transverse superficial pectoral muscle Cranial and caudal thoracic nerves	Sternum from 1st – 6th rib cartilage	Lower arm fascia	Draws limb forward and backward; draws trunk sideward
Descending superficial pectoral muscle Cranial and caudal thoracic nerves	Manubrium sterni	Humeral crest	see above
Deep layer of shoulder musculature			
Deep pectoral muscle Cranial and caudal thoracic nerves	Sternum from 4th rib-cartilage	Lesser tubercle of humerus	Draws limb backward, supports the trunk and moves trunk cranially over advanced limb; extensor of the shoulder joint
Subclavian muscle Cranial thoracic nerves	1st – 4th rib cartilage	Epimysium of supraspinous	Fixation of the scapula
Rhomboid muscle Dorsal a. ventral branches of cervical and thoracic nerves	Nuchal ligament from 2nd – 6th cervical to the 7th thoracic vertebrae	Medial surface of the base of scapula and shoulderblade cartilage	Draws limb forward and fixes scapula against the trunk; elevates limb and neck
Ventral serrate muscle Dorsal and ventral branches of cervical nerves, long thoracic nerve	1st – 7th rib and transverse processes of cervical vertebrae	Serrate surface	Supports the trunk; carries scapula and trunk backward and forward

lateral detachment joins the aponeurosis of the biceps muscle of the forearm to insert on the major tubercle. The superficial portion radiates into the medial fascia of the arm.

The deep pectoral muscle is the largest pectoral muscle in the horse and arises from the abdominal tunic, the lateral aspect of the sternum, the costal cartilages and the ribs. It inserts with two branches to the lesser and greater tubercles of the humerus and the supraglenoid tubercle of the scapula.

In ruminants the **subclavian muscle** is a narrow band, which takes origin from the first costal cartilage and blends with the tendon of insertion of the brachiocephalic muscle.

In the pig and horse it arises from the second to fourth costal cartilage, passes over the shoulder joint and unites with the aponeurosis of the supraspinous muscle. The subclavian muscle is not present in carnivores.

The **rhomboid muscle** lies deep to the trapezius muscle and inserts on the medial aspect of the dorsal part of the scapula. It has two parts, a **cervical part** (m. rhomboideus cervicis), which originates from the spinous processes of the cervical vertebrae and a **thoracic part** (m. rhomboideus thoracis), which originates from the spinous processes of the cranial thoracic vertebrae. In carnivores a third part exists, the capital part (m. rhomboideus capitis), arising from the tendinous raphe of the neck. In the horse, the cervical part of the rhomboid muscle takes its origin from the nuchal ligament at the level of the axis and unites with the trapezius muscle to insert on the medial aspect of the dorsal cartilage of the scapula (Fig. 2-10). The rhomboid muscles forms the wither region of the animal.

The **ventral serrate muscle** constitutes the most important part of the muscular suspension of the thorax between the

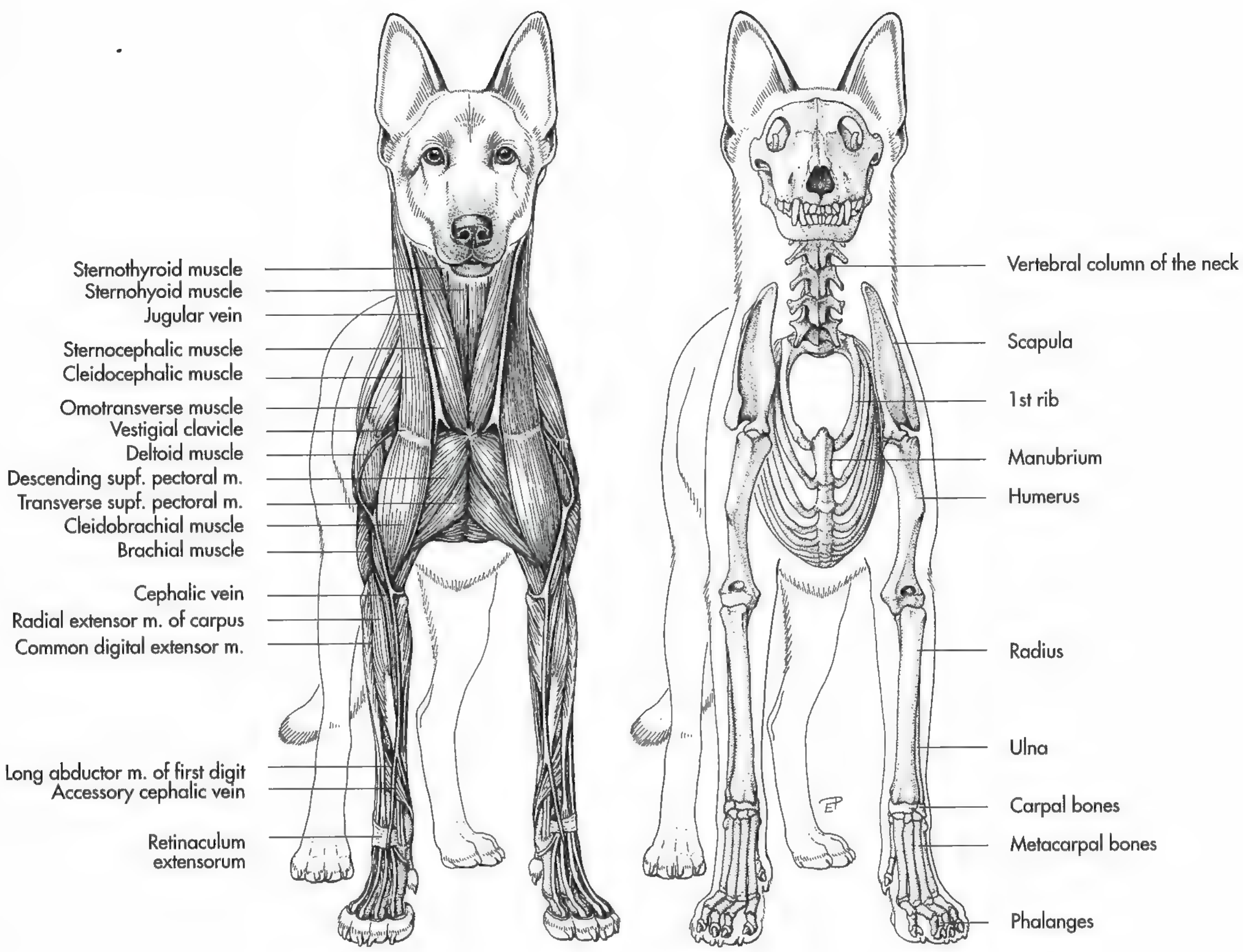

Fig. 3-68. Superficial cervical, thoracic and intrinsic musculature of the shoulder and skeleton of the dog (schematic, craniolateral aspect).

forelimbs. It is a large fan-shaped muscle and can be divided into a cranial **cervical part** (m. serratus ventralis cervicis) and a caudal **thoracic part** (m. serratus ventralis thoracis). The cervical part takes an extensive origin from the transverse processes of the cervical vertebrae and the thoracic portion from the first seven ribs. The muscle bellies are very strong and have numerous tendineous intersections. The muscle fibres converge to insert on the medial aspect of the scapula (facies serrata) and the scapular cartilage (Fig. 2-10).

Intrinsic musculature of the thoracic limb

The intrinsic muscles of the forelimb are responsible for the movements of the separate parts of the limb, together with the joints and ligaments. Their major function is extension and flexion of the joints, but abduction, adduction and rotation are also possible, depending on the structure of the joint which they influence.

They can be divided into:

- Muscles of the shoulder joint,
- Muscles of the elbow joint,
- Muscles of the radioulnar joints,
- Muscles of the carpal joints and
- Muscles of the digits.

Muscles of the shoulder joint

The muscles of the shoulder joint take their origin from the scapula and end on the humerus. They either flex or extend or act as ligaments to brace this hinge joint (Table. 3-8).

The muscles can be grouped by their location:

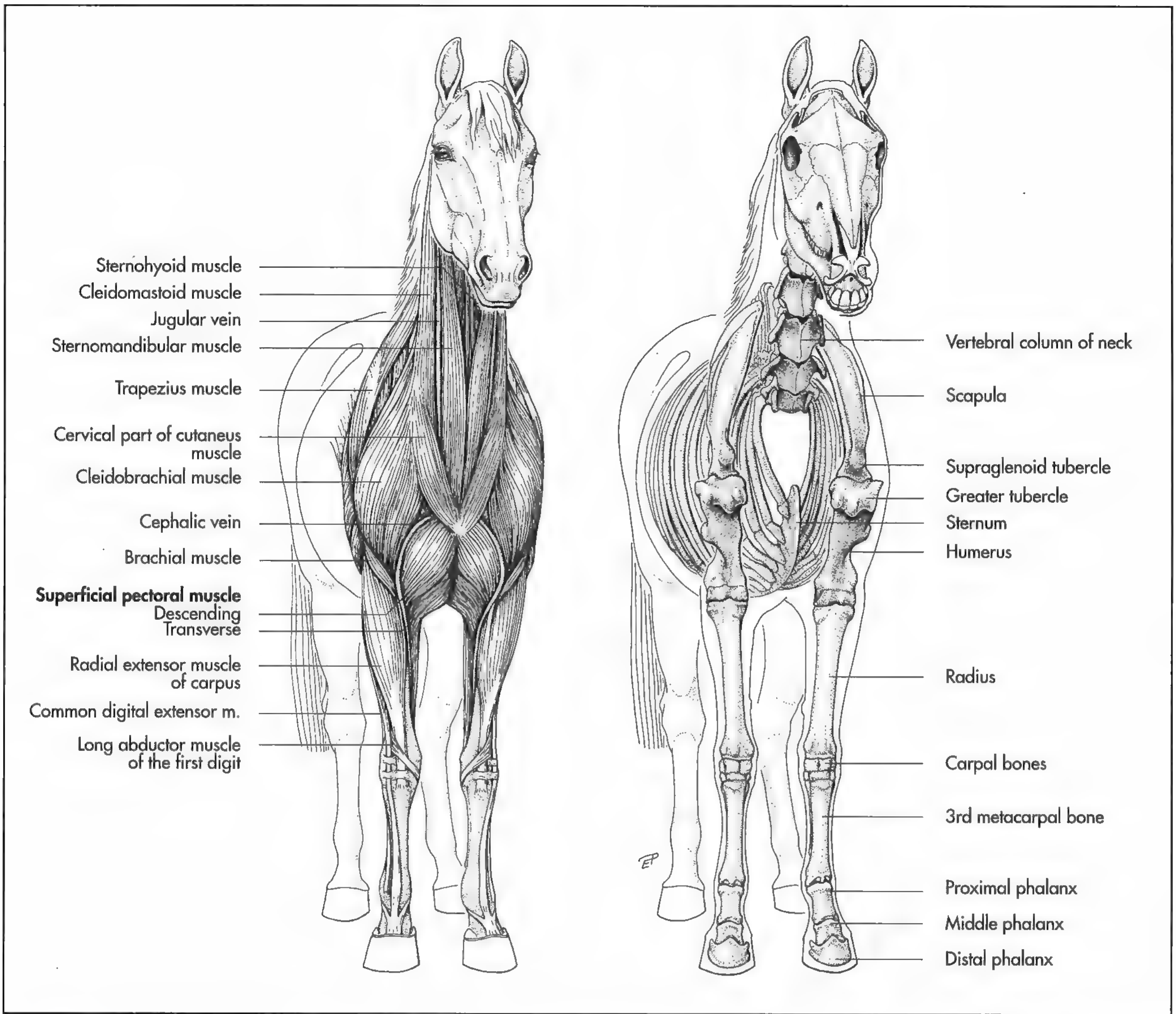

Fig. 3-69. Superficial cervical, thoracic and intrinsic musculature of the shoulder and skeleton of the horse (schematic, craniolateral aspect).

Lateral shoulder muscles:
- Supraspinous muscle (m. supraspinatus),
- Infraspinous muscle (m. infraspinatus),
- Deltoid muscle (m. deltoideus) and
- Minor teres muscle (m. teres minor).

Lateral shoulder muscles

The **supraspinous muscle** arises from and fills the supraspinous fossa of the scapula, beyond which it extends cranially (Fig. 3-70 and 72). Distally it curves over the extensor side of the shoulder joint and terminates with one strong tendon on the greater tubercle of the humerus in carnivores and with two tendons on the lesser and greater tubercle in the other domestic mammals. Between the two tendons runs the tendon of origin of the biceps muscle of the forearm in the intertubercular groove. The muscle partly blends with the joint capsule of the shoulder joint. The supraspinous muscle extends and stabilises the shoulder joint.

The **infraspinous muscle** lies in the infraspinous fossa and extends caudally beyond it. It arises from the fossa and the scapular spine and passes over the lateral aspect of the shoulder joint, where it becomes a strong tendon (Fig. 3-70 and 72). In carnivores it terminates with one tendon on the greater tubercle, where a **synovial bursa** is interposed between the tendon of insertion and the bone (bursa subtendinea musculi infraspinati). In ruminants and the horse the infraspinous tendon splits into a deep part, which inserts on the greater tubercle of the humerus and a stronger superficial part, which inserts distal to the greater tubercle on the lateral aspect of the humerus. In ruminants both tendons of insertion pass over a synovial bursa, while in the horse only the superficial tendon has one. In the horse the infraspinous muscle is a strong, tendinous muscle covered by the aponeurosis of the deltoid muscle. The bursa interposed between the superficial part of the tendon of inser-

Fig. 3-70. Muscles of the left shoulder and elbow joint of a cat (lateral aspect) (courtesy of Dr. Jutta Klawitter-Pommer, Munich).

Fig. 3-71. Muscles of the left shoulder and elbow joint of a cat (medial aspect) (courtesy of Dr. Jutta Klawitter-Pommer, Munich).

tion and the bone can be injected on the cranial border of this tendon.

The infraspinous muscle functions as a lateral collateral ligament of the shoulder joint and supports either flexion or extension of the joint depending on the position of the joint. It also acts as an outward rotator and abductor of the shoulder joint, especially in carnivores.

The **deltoid muscle** is a flat muscle, which lies directly under the skin (Fig. 3-70 and 72) and extends between the scapula and the deltoid tuberosity of the humerus.

It has one head of origin in the horse and pig, arising from the spine of the scapula by means of an aponeurosis. In ruminants and carnivores, there are two heads, arising from the spine of the scapula with an aponeurosis (pars scapularis) and from the acromion (pars acromialis). Both insert on the deltoid tuberosity of the humerus after passing over the caudolateral aspect of the shoulder joint.

In the horse the aponeurosis of the deltoid muscle is partly fused to the infraspinous muscle. The deltoid muscle is a flexor of the shoulder joint and supports abduction and rotation, especially in carnivores.

The **minor teres muscle** is a round muscle in carnivores and triangular shaped in the other domestic mammals. It lies deep to the deltoid muscle on the caudolateral aspect of the shoulder (Fig. 3-72 and 74). It originates from the distal third of the caudal margin of the scapula and crosses over the flexor side of the shoulder joint to insert on the teres minor tuberosity. In the cat it is covered by the infraspinous muscle and the triceps muscle of the forearm and takes its origin from the caudal margin of the scapula and the infraglenoid tubercle. The teres minor muscle flexes the shoulder joint.

Medial shoulder muscles

Medial shoulder muscles:
- Major teres muscle (m. teres major),
- Articular muscle of the shoulder joint (m. articularis humeri),
- Subscapular muscle (m. subscapularis) and
- Coracobrachial muscle (m. coracobrachialis).

The **major teres muscle** is a long, flat muscle, which arises from the caudal angle and margin of the scapula, passes over the flexor side of the shoulder joint and terminates on the teres major tuberosity (Fig. 3-70, 71 and 72). In the cat it is relatively stronger than in the dog, due to its fusion with the tendon of insertion of the broadest muscle of the back. It is a flexor of the shoulder joint and supports adduction of the limb.

The **articular muscle of the shoulder joint** is a small muscle, which is present in the horse, inconsistantly present in the pig and lacking in the rest of the domestic mammals. It lies on the flexor surface of the shoulder joint directly adjacent to the joint capsule. It extends between the distal scapula and the proximal humerus. The articular muscle of the shoulder joint tenses the joint capsule.

The **subscapular muscle** is a flat extensive muscle, which occupies the like-named fossa, beyond which it extends cranially and caudally (Fig. 3-72). It arises from the fossa, crosses

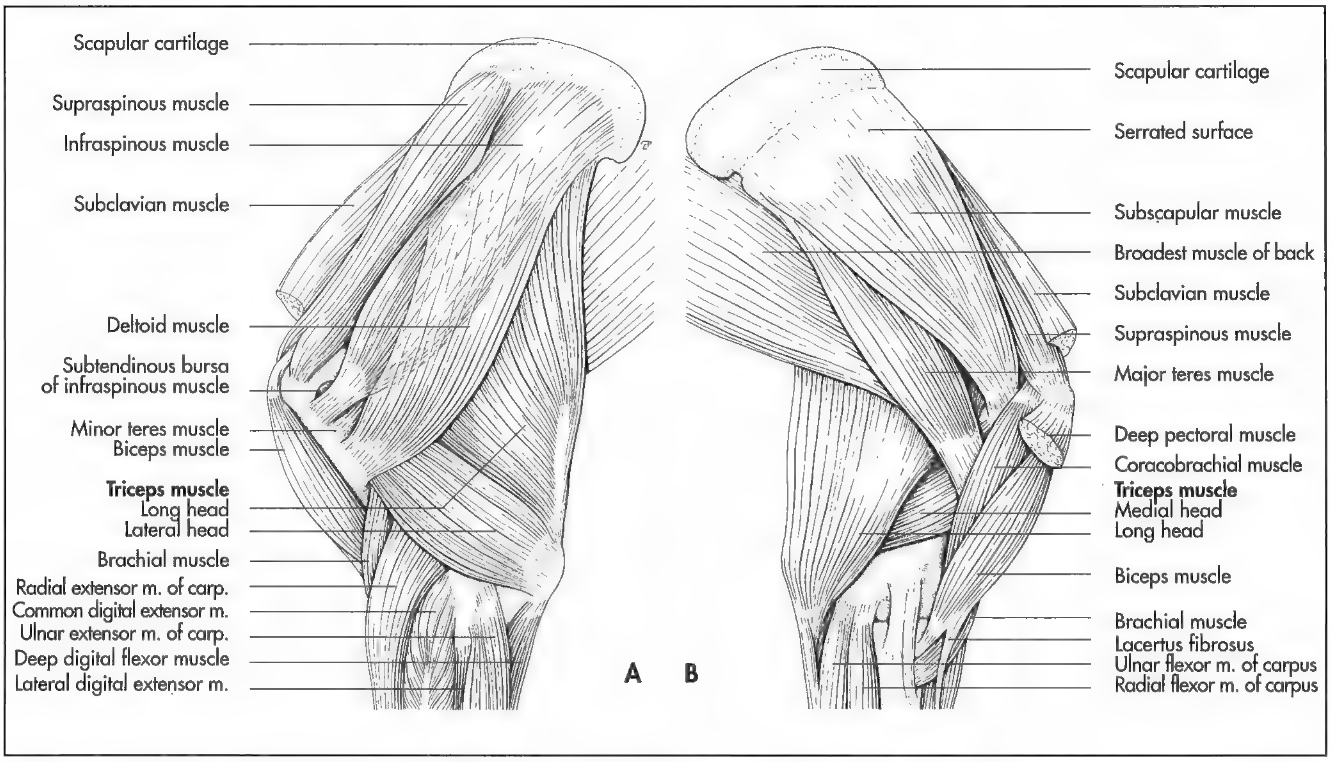

Fig. 3-72. Muscles of the left shoulder and elbow joint of the horse (schematic, **A** lateral and **B** medial aspect).

the shoulder joint on the medial aspect and inserts, deep to the coracobrachial muscle, on the lesser tubercle of the humerus. It is divided into several portions by tendinous bands. It functions as a medial collateral ligament of the shoulder joint. It primarily acts as an extensor of the joint, but it can also contribute to maintaining flexion.

The **coracobrachial muscle** is a flat muscle, which arises on the coracoid process of the scapula (Fig. 3-71 and 72). Its tendon of origin emerges between the supraspinous and the subscapular muscles, where it is protected by a synovial bursa. It extends caudodistally over the medial aspect of the shoulder joint and ends on the teres major tuberosity of the humerus as well as further distal on the medial aspect of the humeral shaft. It adducts the arm and rotates the shoulder joint outward.

Muscles of the elbow joint

The muscles of this group arise either from the scapula or the humerus and insert on the proximal part of the ulna or radius. They either bridge both, the shoulder and the elbow joint, or only the elbow joint. They are primarily responsible for flexion or extension of the elbow joint, but also stabilise the limb during the stance phase of locomotion. The muscles of the elbow joint comprise:

- Brachial muscle (m. brachialis),
- Biceps muscle of the forearm (m. biceps brachii),
- Triceps muscle of the forearm (m. triceps brachii),
- Anconeus muscle (m. anconeus) and
- Tensor muscle of the antebrachial fascia (m. tensor fasciae antebrachii).

Originating on the caudal surface of the proximal humerus, just distal to the humeral neck the **brachial muscle** winds over the lateral surface in the spiral groove of the humerus, finally reaching the medial side, where it inserts on the radial and ulnar tuberosities (Fig. 3-70 and 72). In the horse the brachial muscle ends with one tendon on the medial aspect of the radius, just distal to the biceps muscle of the forearm and one branch passes under the medial collateral ligament to insert on the interosseous membrane of the elbow joint. The brachial muscle acts as a flexor of the elbow joint.

The **biceps muscle of the forearm** is a strong biarticular muscle bridging the shoulder and the elbow joint. In contrast to humans it only possesses one tendon of origin, with which it begins on the supraglenoid tubercle of the scapula (Fig. 3-71 to 74). It passes over the extensor side of the shoulder joint through the intertuberal groove and runs distally along the craniomedial aspect of the humerus. At the level of the elbow joint the muscle splits into two parts. The stronger of the two inserts on the radial tuberosity and the other on the proximal ulna. Some fibres **(lacertus fibrosus)** extend further distally to radiate into the extensor carpi radialis and the fascia of the forearm.

Tab. 3-8. Muscles of the shoulder joint.

Name Innervation	Origin	Insertion	Action
Lateral shoulder musculature			
Supraspinous muscle Suprascapular nerve	Supraspinous fossa	Greater and lesser tubercle	Extensor of shoulder joint
Infraspinous muscle Suprascapular nerve	Infraspinous fossa	Proximal on humerus	Flexor of shoulder joint; its tendon functions as a lateral collateral ligament
Deltoid muscle Axillary nerve	Spine of scapula and caudal border of scapular	Deltoid tuberosity	Flexor of shoulder joint; abductor of the upper arm
Minor teres muscle Axillary nerve	Caudal border of scapula	Teres minor tuberosity	Flexor of shoulder joint
Medial shoulder musculature			
Major teres muscle Axillary nerve	Caudal border of scapula	Tuberositas teres major	Flexor of shoulder joint
Articular muscle of the shoulder joint Axillary nerve	Rim of glenoid cavity	Neck of humerus	Tensor of the joint capsule of the shoulder joint
Subscapular muscle Subscapular nerves	Subscapular fossa	Lesser tubercule	Extensor or flexor of shoulder joint; its tendon functions as a medial collateral ligament
Coracobrachial muscle Musculocutaneous nerve	Coracoid process	Medial surface of humerus	Draws the upper arm inward and outward

In carnivores the biceps muscle of the forearm invaginates the capsule of the shoulder joint cranially, thus forming a synovial sheath in the region of the intertuberal groove. A **transverse band** (ligamentum transversum humeri) between the lesser and greater humeral tubercles holds the muscle in place (Fig. 3-73). In the dog, one tendon inserts at the medial coronoid process of the ulna and the other tendon, which is weaker, inserts on the radial tuberosity.

In ruminants an **intertuberal bursa** (bursa intertubercularis) is interposed between the tendon of origin of the biceps muscle and the intertuberal groove. Its two tendons of insertion terminate on the radial tuberosity, the medial collateral ligament and the cranial aspect of the proximal radius.

In the horse it is a strong muscle with several tendinous intersections. Its passage through the intertuberal groove is faciliated by the large **bicipital bursa** (bursa intertubercularis). This bursa is about 10 cm long and extends beyond the borders of the biceps muscle. It is flanked by the supraspinous and the deep pectoral muscle. Synoviocentesis can be performed by inserting a needle at the level of the deltoid tuberosity at the border of the biceps tendon in a proximal direction.

The muscle is divided distally in a lateral and medial portion. The medial portion terminates on the radial tuberosity, the lateral portion inserts on the proximal end of the radius and ulna.

It also detaches fibres **(lacertus fibrosus)** to the fascia of the forearm and the radial extensor muscle of the carpus. A synovial bursa can be present on the proximal part of the radius, below the lateral tendon of insertion.

The biceps muscle of the forearm flexes the elbow joint and extends the shoulder joint. It also stabilises the shoulder joint during standing or the stance phase of locomotion, which is especially important in the horse.

The **triceps muscle of the forearm** fills the triangle between the caudal border of the scapula, the humerus and the olecranon (Fig. 3-70 to 72). Its caudal border (margo tricipitalis) extends from the olecranon into the direction of the withers and is clearly visible under the skin in the live animal.

The triceps muscle of the forearm possesses three heads of origin, a long, a lateral and a medial head, and in the dog, an additional accessory head. The **long head** (caput longum) arises from the caudal margin of the scapula, the **lateral head** (caput laterale) from the lateral aspect of the shaft of the humerus and the **medial head** (caput mediale) from the medial aspect of the shaft of the humerus. In the dog the **accessory head** (caput accessorius) takes its origin from the caudal part of the neck of the humerus and blends with the long and lateral heads. The triceps muscle is a powerful muscle with the long head being the largest and longest of the three heads, the medial head much the smallest. The lateral head is a strong quadrilateral muscle, which originates from the deltoid tuberosity of the humerus, the fascia of the arm and the tricipital line, which extends from the deltoid tuberosity to the neck of the humerus. It blends with the long head and inserts on the

Tab. 3-9. Muscles of the elbow joint.

Name Innervation	Origin	Insertion	Action
Brachial muscle Musculocutaneous nerve, Radial nerve	Caudal on neck of humerus	Medial on radius and ulna	Flexor of elbow joint
Biceps muscle of the forearm Musculocutaneous nerve	Supraglenoid tubercule	Radial tuberosity	Flexor of elbow joint; extensor of shoulder joint; stabilizes the shoulder and carpal joint
Triceps muscle of the forearm Radial nerve			Fixaton of elbow joint; extensor of shoulder joint when limb is elevated
Long head	Caudal border of scapula	Olecranon	Extensor of elbow and flexor of shoulder joint
Lateral head	Lateral on humerus	Olecranon	Extensor of elbow joint
Medial head	Medial on humerus	Olecranon	Extensor of elbow joint
Anconeus muscle Radial nerve	Distal on humerus, Olecranal fossa	Lateral on olecranon	Extensor of elbow joint
Tensor muscle of the antebrachial fascia Radial nerve	Caudal border of scapula	Antebrachial fascia	Tensor of antebrachial fascia; extensor of elbow joint

lateral surface of the olecranon. The medial head arises close to the teres tuberosity and ends on the medial aspect of the olecranon. In the dog all heads terminate with a common tendon of insertion on the olecranon. A **synovial bursa** (bursa subtendinea tricipitis brachii) is interposed between the tendon of insertion and the olecranon.

The triceps brachii flexes and stabilises the elbow joint. Since the long head of the triceps brachii muscle spans two joints it acts as a flexor of the shoulder joint during the swing phase of locomotion and as an extensor of the elbow joint.

The **anconeus muscle** is a short, but strong muscle, situated deep to the triceps muscle of the forearm on the caudal aspect of the distal end of the humerus (Fig. 3-74). It arises from the distal surfaces of the humerus and the humeral epicondyles, bridges the olecranon fossa and inserts on the lateral aspect of the olecranon. It blends with the lateral head of the triceps muscle in the horse and ox, but remains a separate muscle in the rest of the domestic mammals. The anconeus muscle extends the elbow joint.

The **tensor muscle of the antebrachial fascia** is a flat muscle, which lies on the medial surface of the triceps muscle. The origin consists of a broad aponeurosis from the broadest muscle of the back (carnivores) and the caudal border of the scapula (ruminants and horse) and radiates into the fascia of the forearm. It is the chief tensor of this fascia and acts as an extensor of the elbow joint.

Muscles of the radioulnar joints

The primary function of the muscles of the radioulnar joints are supination and pronation. They are only well-developed and functional in carnivores. In other domestic animals they are vestigial or missing due to the reduced or lost capability for these movements (Fig. 3-75 and 76).

In carnivores they can be divided into:

Supinators of the forearm:
- Brachioradial muscle (m. brachioradialis),
- Supinator muscle (m. supinator).

Pronators of the forearm:
- Round pronator muscle (m. pronator teres),
- Quadrate pronator muscle (m. pronator quadratus).

The **brachioradial muscle** is a thin, flat muscle, which extends from the lateral supracondylar crest over the flexor side of the elbow joint, superficial to the radial extensor muscle of the carpus to the radial styloid process (Fig. 3-78).

The **supinator muscle** (Fig. 3-75) is present in carnivores and the pig. It is a flat muscle, which lies on the flexor side of the elbow joint directly on the joint capsule, covered by the radial extensor muscle of the carpus and the common digital extensor muscle. It arises from the lateral epicondyle of the humerus, spirals mediodistally and inserts on the medial aspect of the radius.

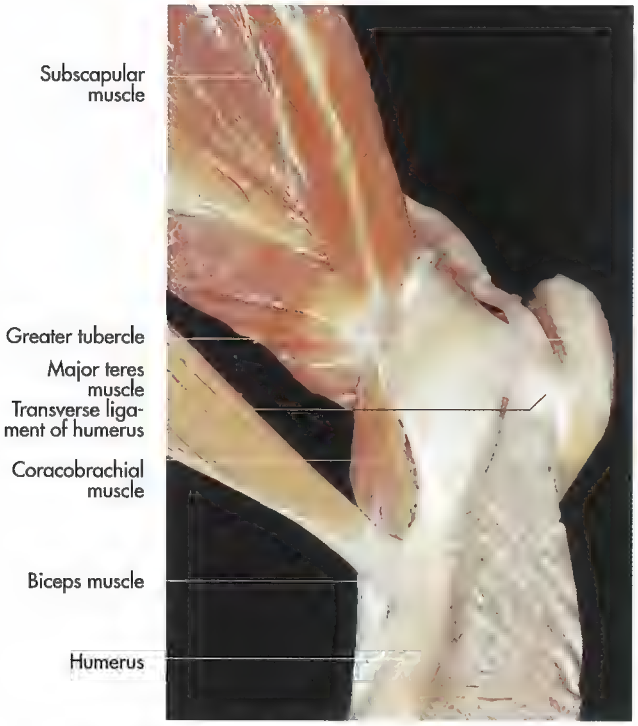

Fig. 3-73. Muscles of the left shoulder joint of a dog (medial aspect).

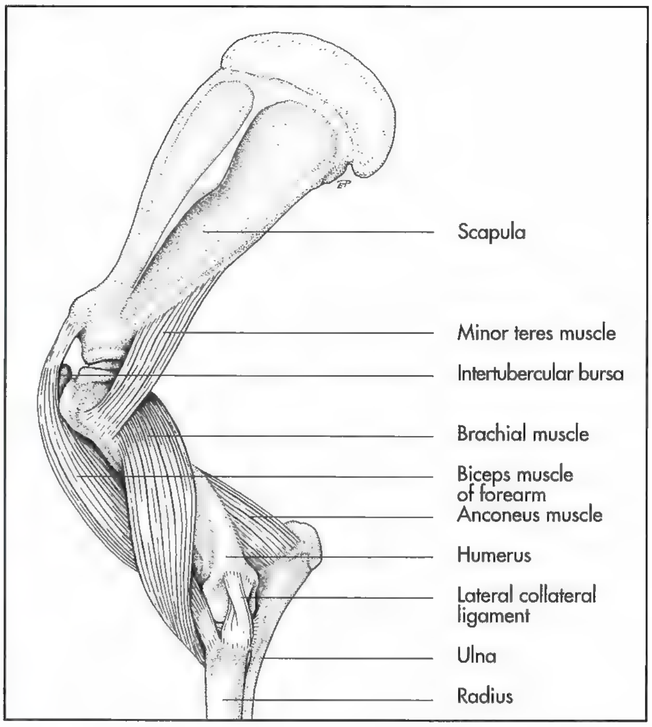

Fig. 3-74. Muscles of the shoulder and elbow joint of the horse, deep layer (schematic, lateral aspect) (Ellenberger and Baum, 1943).

The **round pronator muscle** is consistently present in carnivores (Fig. 3-75, 76 and 79), but inconsistant in ruminants and the pig. In the horse it is reduced to a small band. It extends between the medial epicondyle of the humerus and the craniomedial side of the radius.

The **quadrate pronator muscle** is found only in carnivores. It bridges the medial aspect of the interosseous space of the forearm. Its fibres pass from the caudal and medial aspect of the shaft of the radius to the medial aspect of the ulna (Fig. 3-76).

Muscles of the carpal joint

The muscles of the carpal joint have long extended muscle bellies and cover the antebrachial skeleton. They are biarticular, arising proximal to the elbow joint from the humerus and attaching distal to the carpal joint to the carpus or metacarpus. Due to the reduced range of movement of the carpal joints in the domestic mammals, these muscle act as either flexor or extensors.

The **extensor muscles of the carpal joint and digits** are located on the cranio(dorso)lateral side, whereas the **flexors** are situated on the caudal (palmar) side (Fig. 3-77). They are covered by the antebrachial fascia. The extensors of the carpus and digits arise from the lateral epicondyle of the humerus, the flexors from the medial epicondyle.

The muscles of the carpus comprise the (Fig. 3-78 to 86 and Tab. 3-10):

- Radial extensor muscle of the carpus (m. extensor carpi radialis),
- Ulnar extensor muscle of the carpus (m. extensor carpi ulnaris),
- Radial flexor muscle of the carpus (m. flexor carpi radialis) and
- Ulnar flexor muscle of the carpus (m. flexor carpi ulnaris).

The **radial extensor muscle of the carpus** is the largest of the extensor muscles of the carpal joints. It arises from the lateral humeral epicondyle and the lateral epicondylar crest and is situated directly cranial to the subcutaneous border of the radius. It inserts on the proximal extremity of the second and third metacarpal bone.

In the cat, the muscle splits into two muscle bellies, a long and a short portion, which form two flat tendons at the middle of the radius. The long portion (m. extensor carpi radialis longus) attaches to the proximal end of the second metacarpal bone, the short portion (m. extensor carpi radialis brevis) lies lateral to the long portion and attaches to the third metacarpal bone. In the dog the muscle belly of the radial extensor muscle runs distally medial to the common digital extensor muscle, where it splits into two tendons of insertion at the distal third of the radius. Both tendons cross the middle groove of the radius and the extensor side of the carpus to insert separately on the second and third metacarpal bone.

The tendon of insertion is enclosed by a synovial sheath, extending from the middle of the radius to the carpal joints

Fig. 3-75 Muscles of the shoulder and elbow joint of a cat (deep layer, lateral aspect).

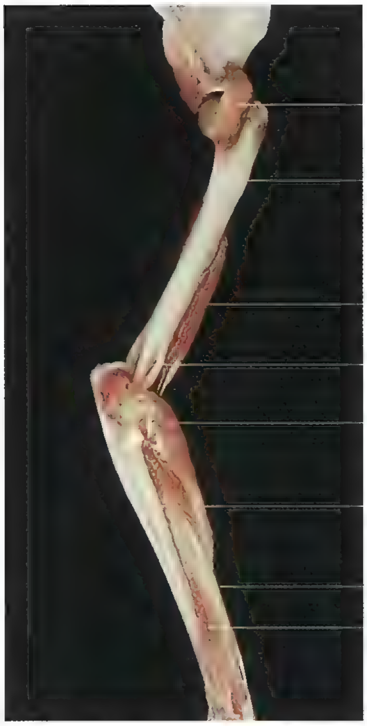

Fig. 3-76 Muscles of the shoulder and elbow joint of a cat (deep layer, medial aspect).

and to the point of insertion on the distal carpal bones or on the proximal end of the metacarpal bone(s) (Fig. 3-42 to 45). In the horse the tendon is joined by the lacertus fibrosus, a detachment of the biceps muscle of the forearm (Fig. 3-84). It passes through the middle groove of the carpus, adherent to the joint capsule, and inserts on the proximal tuberosity of the third metacarpal bone, where a synovial bursa is interposed. The radial extensor muscle of the carpus extends and fixes the carpal joint and flexes the elbow joint.

The **ulnar extensor muscle of the carpus** lies on the caudolateral side of the forearm. It extends between the lateral epicondyle of the humerus and the lateral carpal and metacarpal bones, depending on the species.

In carnivores it arises caudal to the lateral collateral ligament of the elbow from the lateral humeral epicondyle, passes laterally over the carpus and ends on the proximal end of the fifth metacarpal bone. By means of fibres from the antebrachial fascia arising from the accessory carpal bone the tendon of insertion takes over the function of the missing lateral collateral ligament of the carpus. Two weak bands are detached to blend with the extensor and the flexor retinaculum.

In ruminants and in the horse the terminal tendon is split into a main portion, which attaches to the accessory carpal bone and a weaker portion for the fifth metacarpal bone in ruminants and for the lateral splint bone in the horse (Fig. 3-38).

In carnivores the ulnar extensor muscle flexes the carpus, when it is already in a flexed position and supports extension, when already in an extended position due to the anatomical insertion, which is close to the axis of the joint. It also abducts the forearm.

In the other domestic mammals it acts as a flexor of the carpal joints, since the insertion is shifted caudal to the axis of the carpus onto the accessory carpal bone.

The **radial flexor muscle of the carpus** lies on the medial side of the forearm, caudal to the border of the radius, directly under the skin (Fig. 3-80). It arises from the medial epicondyle of the humerus, passes over the flexor side of the carpus, where it is enclosed in a synovial sheath and inserts on the palmar aspect of the second and third metacarpal bones in carnivores, on the third metacarpal bone in the pig and in ruminants and on the second metacarpal bone in the horse (Fig. 3-82).

It is a flexor of the carpal joints.

The **ulnar flexor muscle of the carpus** lies on the mediocaudal side of the forearm, superficial to the flexor muscles of the digit. It is marked by several tendinous intersections. It arises by two heads, with the stronger **humeral head** (caput humerale) from the medial epicondyle of the humerus and with the smaller **ulnar head** (caput ulnare) from the olecranon (Fig. 3-75 and 78, 80 and 81). Both portions end with a common tendon of insertion on the accessory carpal bone. In the horse a synovial bursa can be found under the humeral head which communicates with the elbow joint and extends under the deep digital flexor tendon. The flexor carpi ulnaris is a flexor of the carpus and in carnivores it is a supinator of the limb.

Muscles of the digits

The muscles of the digits are strong tendinous muscles, which cover the antebrachial skeleton and span several joints. They arise proximal to the elbow joint from the hu-

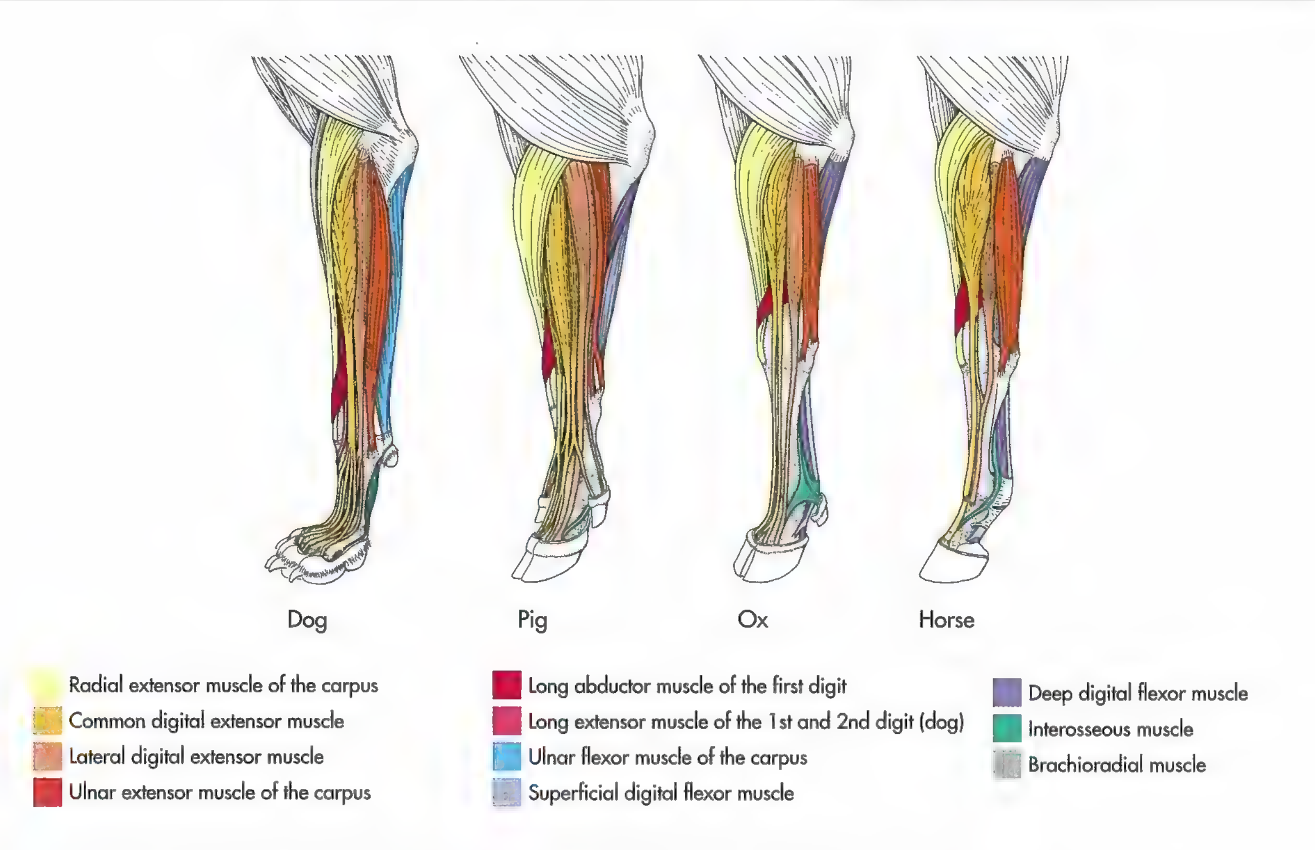

Fig. 3-77. Muscles of the antebrachium (schematic, lateral aspect) (Ellenberger and Baum, 1943).

merus or the forearm and run with long tendons over the carpus to insert on different parts of the digits.

The species specific evolution of the limbs resulted in a limited range of movement of the phalanges. In the domestic mammals most of the phalangeal joints are uniaxial hinge joints, a few are biaxial saddle joints, with the major movement being extension and flexion and allowing a very limited degree of abduction and adduction. The **extensor muscles** of the digits are located on the **cranio(dorso)lateral** side of the antebrachium, whereas the **flexor muscles** are found on the **caudal (palmar)** side, covered by the antebrachial fascia. The **extensors** arise from the **lateral epicondyle** of the humerus, the **flexors** from the **medial epicondyle:**

Extensors:
- Common digital extensor muscle (m. extensor digitorum communis),
- Lateral digital extensor muscle (m. extensor digitorum lateralis),
- Long abductor muscle of the first digit (m. abductor pollicis longus) muscle and
- Extensor muscle of the first and second digit (m. extensor digiti I et II).

The **common digital extensor muscle** is a strong muscle with several tendinous intersections, which lies lateral to the radial extensor muscle of the carpus (Fig. 3-78 to 86). It arises with several poorly defined heads (four in carnivores, three in pigs, two in ruminants and one in the horse) from the lateral epicondyle of the humerus, the lateral collateral ligament of the elbow joint, the radius and the ulna dependant on species. It ends with a long tendon of insertion on the extensor process of the distal phalanx of each functional digit (Fig. 3-72, 78, 79 and 84). Therefore the tendon of insertion is split according to the number of functional digits in the different species and is unbranched in the horse.

In carnivores, the common digital extensor muscle originates from the lateral humeral epicondyle. It also originates, together with the extensor carpi radialis muscle, from the lateral collateral ligament of the elbow joint. The muscle belly divides into four tendons distally, which run, enclosed in a common synovial sheath and covered by the extensor retinaculum, over the dorsolateral side of the carpus (Fig. 3-79).

The individual tendons separate, when passing over the dorsal aspect of the corresponding metacarpal bones and terminate on the distal phalanx of the four main digits. In the cat, a few fibres insert on the middle phalanx. Thin tendinous bands arising from the interosseous muscles fuse bilaterally with each tendon. The tendons of the lateral digital extensor muscle join the tendons of the common digital extensor muscle at the level of the proximal phalanx on the third, fourth and fifth digit.

Tab. 3-10. Muscles of the carpal joint.

Name **Innervation**	**Origin**	**Insertion**	**Action**
Radial extensor muscle of the carpus Radial nerve	Lateral epicondyle of humerus	Proximal on 3rd metacarpal bone	Extensor and fixator of carpal joint
Ulnar extensor muscle of the carpus Radial nerve	Lateral epicondyle of humerus	5th and 4th metacarpal bone, accessory carpal bone	Flexor of carpal joint
Radial flexor muscle of the carpus Median nerve	Medial epicondyle of humerus	2nd and 3rd metacarpal bone	Flexor of carpal joint
Ulnar flexor muscle of the carpus Ulnar nerve			
Humeral head	Medial epicondyle of humerus	Accessory carpal bone	Flexor of carpal joint
Ulnar head	Olecranon	Accessory carpal bone	Flexor of carpal joint

The common digital extensor muscle of the pig is divided into three parts. The medial portion is the strongest and ends chiefly on the distal phalanx of the third digit. The tendon of the middle head divides into two branches for the insertion to the distal phalanx of the third and fourth digit. The tendons of insertion also send small branches to the second and fifth digit.

In ruminants, the common digital extensor muscle consists of two distinct bellies, which continue distally as two separate tendons. The lateral belly arises with a superficial head from the lateral epicondyle of the humerus and with a deep head from the ulna. Both heads converge and run over the dorsolateral aspect of the carpus. The resultant tendon splits into two separate tendons at the level of the metacarpophalangeal joint, which insert on the extensor process of the distal phalanx of the third and fourth digit (Fig. 3-87). The medial belly also originates from the lateral epicondyle of the humerus and terminates with one tendon of insertion on the dorsomedial aspect of the second phalanx of the third digit, reinforced by abaxial and axial branches of the interosseous muscle.

In the horse the common digital extensor muscle is marked by several strong tendinous intersections and lies deep to the extensor carpi radialis and the lateral digital extensor muscle (Fig. 3-83 and 84). It originates proximal to the lateral humeral condyle between the radial fossa and the lateral epicondyle of the humerus, from the lateral tuberosity of the proximal extremity of the radius and the lateral collateral ligament of the elbow. The strong tendon passes distally through the lateral groove on the distal end of the radius and over the dorsolateral aspect of the carpus, bound by the extensor retinaculum and protected by a synovial sheath. The tendon sheath starts about 10 cm proximal to the carpus and extends distally to the metacarpus. The common digital extensor tendon continues distally over the dorsal surface of the metacarpus and is joined by branches of the interosseous muscle before it inserts with a broad tendon on the extensor process of the distal phalanx. A second branch inserts on the second phalanx and some fibres on the hoof cartilages.

Lateral to the common digital extensor muscle arises a small muscle, which can be divided into a deep portion from the ulna and a more superficial one from the radius. The ulnar portion (also known as Thiernes muscle) unites with the common digital extensor tendon and is thought to be the remnant of the extensor indicis muscle. The radial portion (also called Phillip muscle) runs over the carpus as a separate muscle and joins the tendon of the lateral digital extensor muscle further distal (Fig. 3-82).

The common digital extensor muscle extends the carpal and digital joints.

The **lateral digital extensor muscle** is situated caudal to the common digital extensor muscle on the lateral surface of the antebrachium (Fig. 3-77, 78 and 83). It arises from the lateral collateral ligament of the elbow joint, the lateral tuberosity of the proximal end of the radius and the lateral aspect of the ulna. It is divided into three muscle bellies in the cat, two muscle bellies in the dog and pig and one in ruminants and in the horse. The number of the tendons of insertion correspond to the number of the functional digits left in the different species.

In the cat, the lateral digital extensor muscle originates from the lateral supracondylar crest of the humerus and divides into three bellies, which split into three or four tendons further distally. They unite with the common digital extensor tendons at the level of the proximal phalanges.

In the dog, the lateral digital extensor muscles arises from the lateral collateral ligament and the lateral tuberosity of the proximal radius (Fig. 3-77 and 78). It divides into a lateral and medial tendon, which are enclosed in a common synovial sheath reaching from the carpus to the proximal third of the

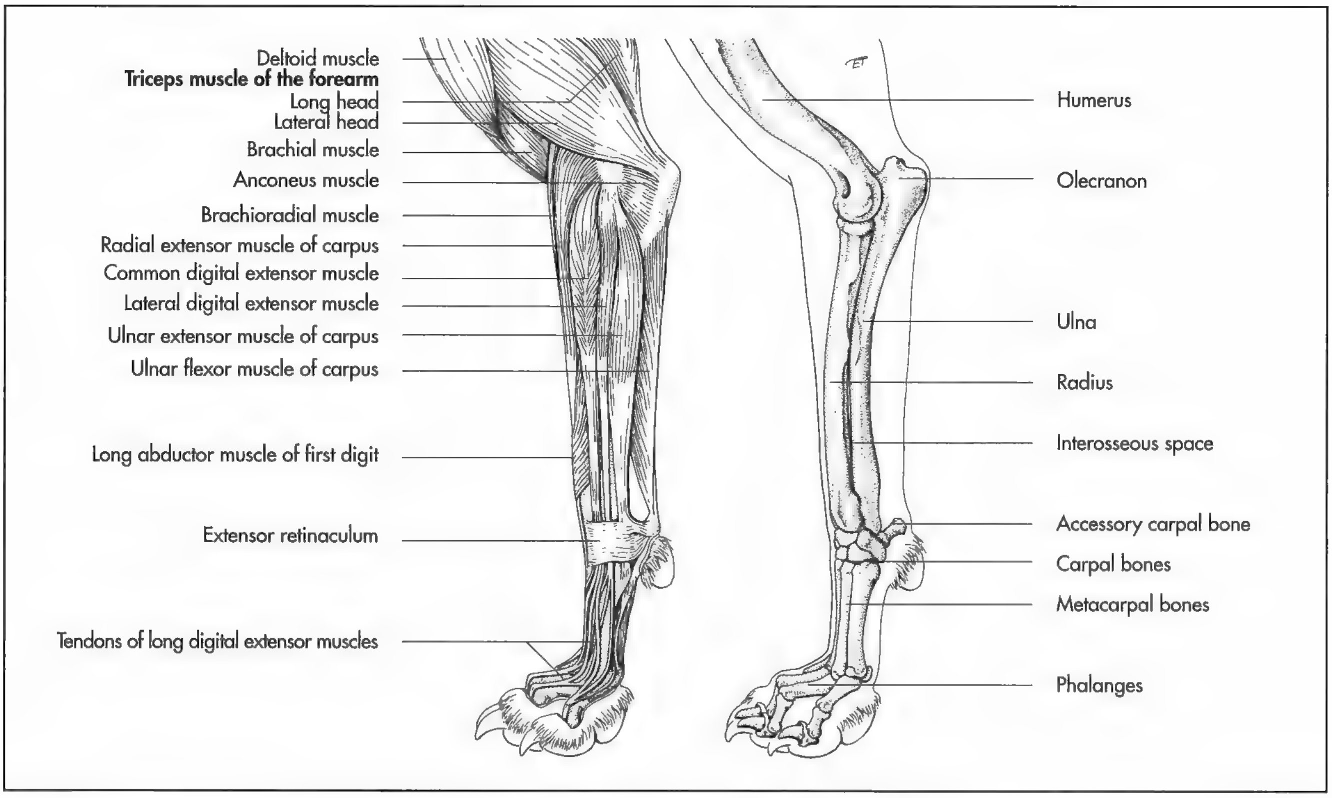

Fig. 3-78. Muscles and skeleton of the carpus and digit of the dog (schematic, lateral aspect).

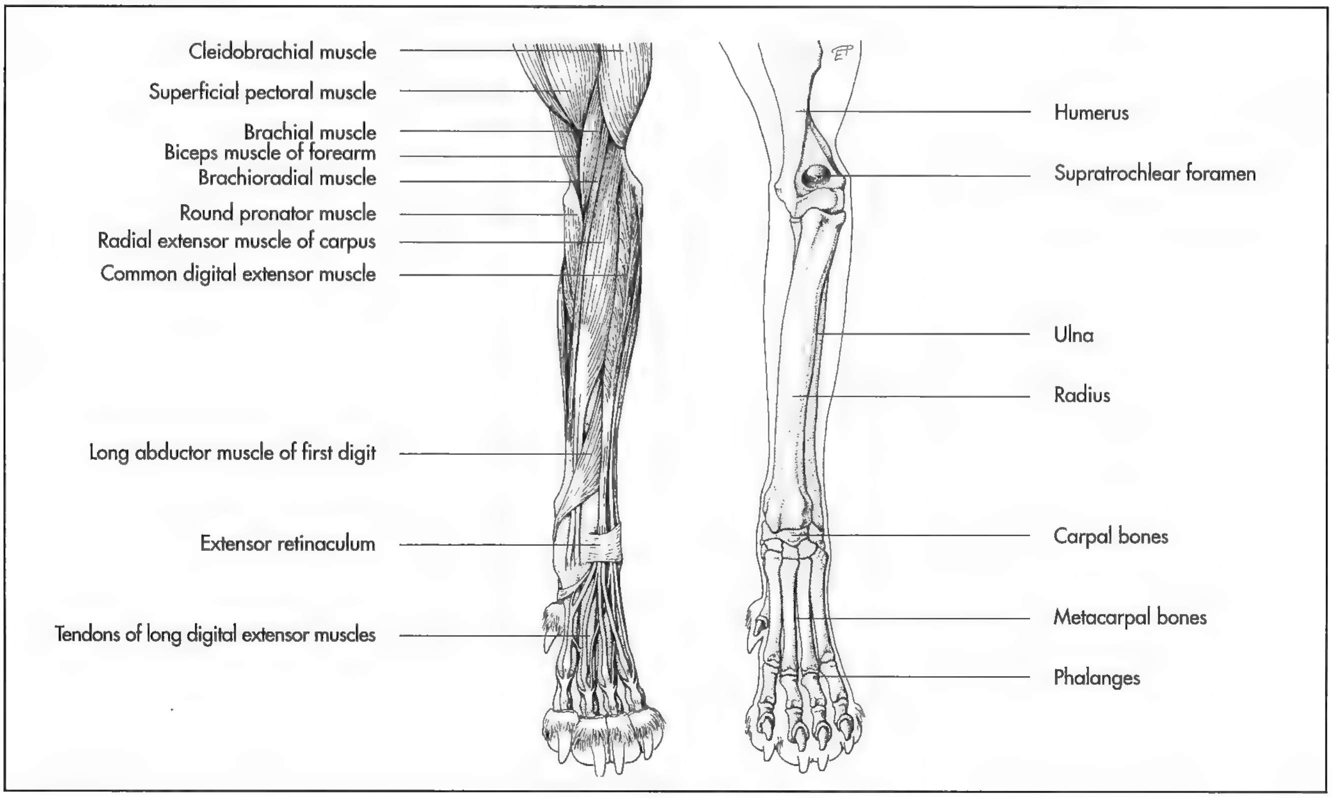

Fig. 3-79. Muscles and skeleton of the carpus and digit of the dog (schematic, dorsal aspect).

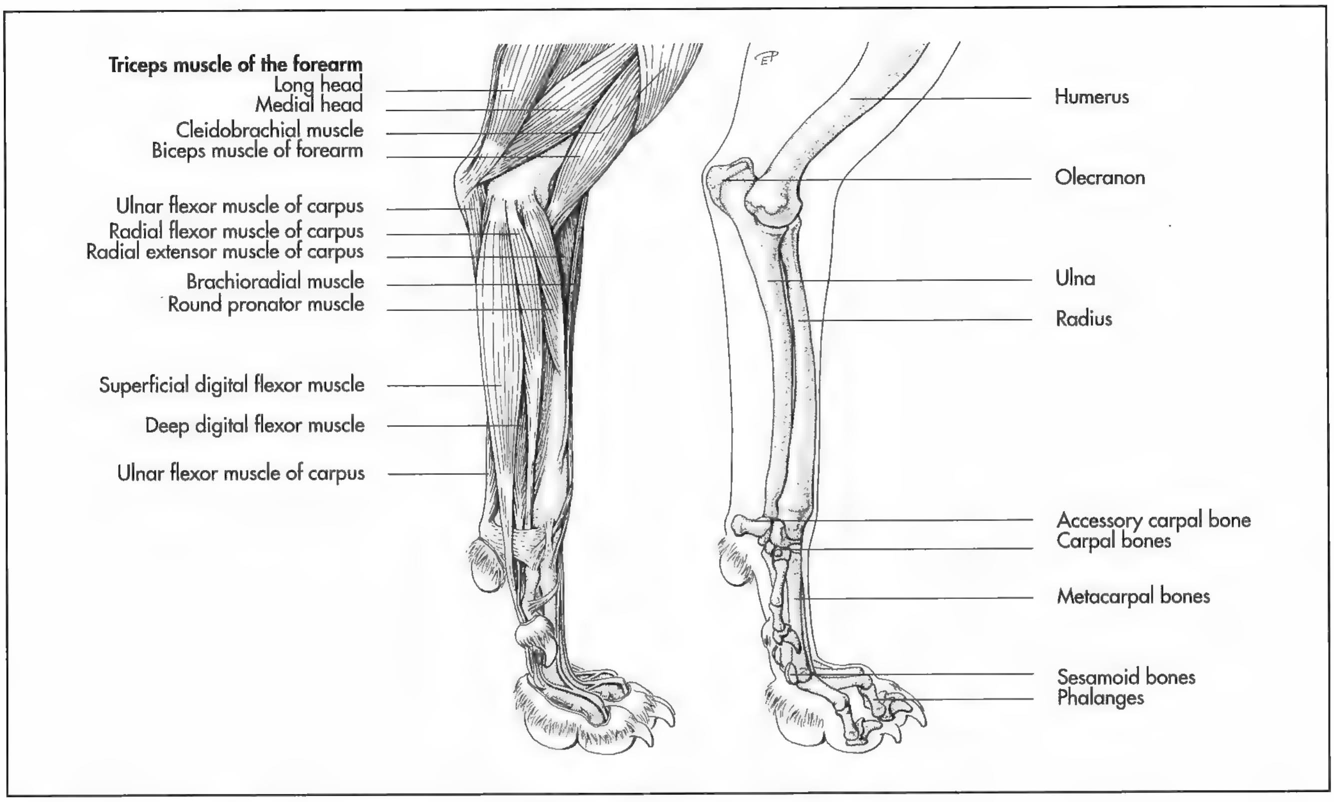

Fig. 3-80 Muscles and skeleton of the carpus and digit of the dog (schematic, medial aspect).

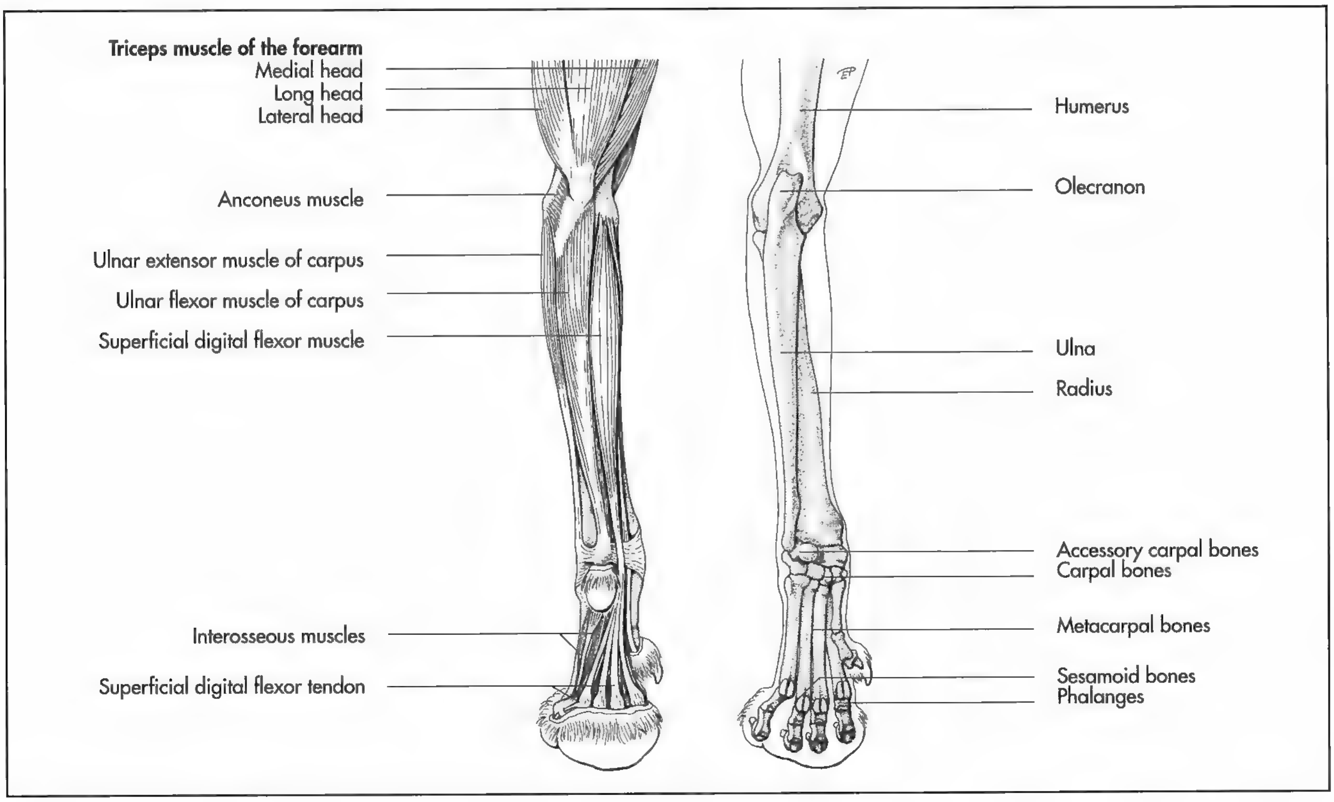

Fig. 3-81 Muscles and skeleton of the carpus and digit of the dog (schematic, palmar aspect).

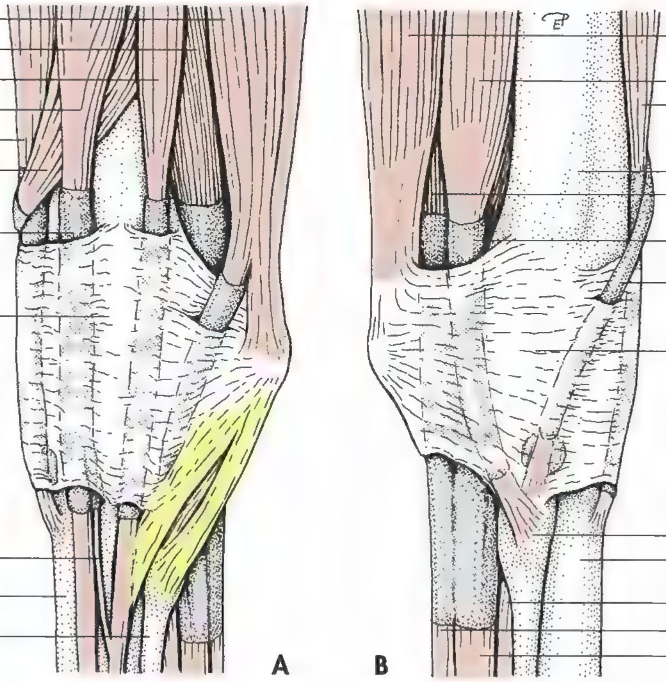

Fig. 3-82. Tendons and their synovial sheaths of the left carpus of the horse (schematic, **A** dorsal and **B** medial aspect) (Ellenberger and Baum, 1943).

metacarpus. The stronger lateral tendon unites with the corresponding tendon of the common digital extensor muscle and ends on the distal phalanx as well as on the proximal and middle phalanx of the fifth digit. The tendon of the weaker medial portion splits into two and joins the corresponding tendons of the common digital extensor muscle, with which they end on the distal phalanx of the third and fourth digit.

In the pig, the lateral digital extensor muscle has two distinct parts. The larger belly originates from the lateral humeral epicondyle and the lateral collateral ligament of the elbow and ends on the middle and distal phalanx of the fourth digit after reception of a branch from the interosseous muscle. The smaller muscle belly extends between the ulna and the middle and distal phalanx of the fifth digit.

In ruminants, the lateral digital extensor muscle consists of a single muscle belly, which passes, lateral to the common digital extensor muscle, over the lateral side of the carpus, where it is enclosed in a synovial sheath. It is enforced axially and abaxially by slips from the interosseous muscle. It inserts on the dorsolateral aspect of the middle phalanx of the fourth digit (Fig. 3-87).

In the horse, the lateral digital extensor muscle arises from the lateral humeral epicondyle, the lateral collateral ligament of the elbow and the lateral tuberosities of the proximal radius and ulna. It passes distally through the groove on the lateral styloid process of the radius, where it is covered by the deep fascia and then over the lateral side of the carpus, where it is enveloped in a tendon sheath (Fig. 3-82). The tendon of insertion is strengthened by fibres from the deep fascia and unites with the tendon of the Philipp muscle at the level of the metacarpus, before its insertion to the dorsolateral aspect of the proximal phalanx.

The lateral digital extensor muscle extends the carpal and phalangeal joints of the lateral digits in carnivores and the pig, the carpus, fetlock and pastern joint of the fourth digit in ruminants and the carpus and fetlock joint in the horse.

The **extensor muscle of the first and second digit** is present as a separate muscle in carnivores only (Fig. 3-77). In the other domestic mammals it is fused to the common digital extensor muscle, in the horse the Thierness muscle is thought to be the remnant of this muscle.

In the cat, this muscle arises from the craniolateral border of the ulna and is covered distally by the lateral digital extensor tendon. It divides into three tendons, which run deep to the common digital extensor tendon medially. They insert to the first and second digit.

In the dog, it arises, covered by the extensors of the carpus and digits from the craniolateral border of the ulna. It crosses deep to the common digital extensor tendon the carpus and appears on the medial side. It splits into two tendons of insertion, the medial one of which ends on the first metacarpal bone and the lateral one joins the common digital extensor tendon for the second digit.

The muscle extends the first and second digit and adducts the first one.

Tab. 3-11. Muscles of the digits.

Name Innervation	Origin	Insertion	Action
Common digital extensor muscle Radial nerve	Lateral epicondyle of humerus	Extensor process of distal phalanx	Extensor of carpal joint; extensor of digital joints
Lateral digital extensor muscle Radial nerve	Lateral epicondyle of humerus	Middle phalanx	Extensor of digital joints
Long digital extensor muscle of the first and second digit Radial nerve	Mid third of ulna	1st–2nd toe	Extensor of 1st and 2nd toe (only carniv.)
Long abductor muscle of the first digit Radial nerve	Lateral on radius	Carniv.1st, horse/pig 2nd rumin. 3rd metacarpal bone	Extensor of carpal joint; abductor of 1st toe (carniv.)
Superficial digital flexor muscle Ulnar nerve, median nerve	Medial epicondyle of humerus	Proximal on middel phalanx	Flexor of supporting digits; flexor of the forefoot; stabilises the fetlock joint
Deep digital flexor muscle Ulnar nerve, median nerve	Medial epicondyle of humerus radius, ulna	Flexor surface of distal phalanx	Flexor of the forefoot
Proximal and distal interflexor muscles Ulnar nerve, median nerve	Distal on antebrachium	Together with superficial digital flexor tendon	Flexor of digital joints

The **long abductor of the first digit** arises from the middle third of the lateral border of the radius and ulna and covers the craniolateral aspect of the antebrachium. Its tendon runs deep to the digital extensor tendons to the medial side of the carpus. It inserts to the first metacarpal bone in carnivores, to the second metacarpal bone in the pig and horse and the third in ruminants (Fig. 3-82 and 84). A small sesamoid bone can be found in the tendon of insertion in carnivores.

The muscle extends the carpus and the digit to which it inserts and abducts the first digit in carnivores

Flexors:
- Superficial digital flexor muscle (m. flexor digitorum superficialis),
- Deep digital flexor muscle (m. flexor digitorum profundus),
- Interflexor muscles (mm. interflexorii).

The **superficial digital flexor muscle** arises from the medial epicondyle of the humerus and divides into a branch for each functional digit, that inserts on the middle phalanx of these digits. Before its insertion each branch splits into two slips, that diverge either side of the tendons of the deep digital flexor muscle, which inserts more distally (Fig. 3-86, 89 and 90).

In carnivores, the superficial digital flexor muscle is a flat muscle, which lies directly beneath the skin on the mediocaudal aspect of the antebrachium (Fig. 3-77 to 81). It arises from the medial humeral epicondyle between the humeral heads of the deep digital flexor muscle and the ulnar flexor muscle of the carpus. The fleshy muscle belly becomes tendinous at the level of the carpus. This tendon runs over the flexor surface of the carpus medial to the accessory carpal bone, where its passage is faciliated by a synovial bursa. In the proximal third of the metacarpus the tendon splits into five portions in the cat and four in the dog, which diverge to reach the proximal border of the middle phalanx of the first to fifth digits in the cat and second to fifth digit in the dog.

Each branch of the superficial digital flexor tendon forms a sleeve-like enclosure **(manica flexoria)** around the corresponding branches of the deep digital flexor tendon just proximal to the metacarpophalangeal joints. Distal to the proximal sesamoid bones the branches of the superficial flexor tendon are split for the passage of the deep tendon. At the metacarpophalangeal joint and the proximal and middle phalangeal joint the branches of the flexor tendons are bridged by three bands, the proximal, middle and distal transverse ligaments.

In the pig, the superficial digital flexor muscle arises from the medial epicondyle of the humerus and consists of two parts. The tendon of the smaller superficial head crosses the flexor retinaculum superficially and forms a tube around the deep digital flexor tendon at the metacarpophalangeal joint. It ends with two branches on the middle phalanx of the fourth digit. The tendon of the stronger deep head passes distally bound by the flexor retinaculum and ends on the medial phalanx of the third digit after being perforated by the deep digital flexor tendon.

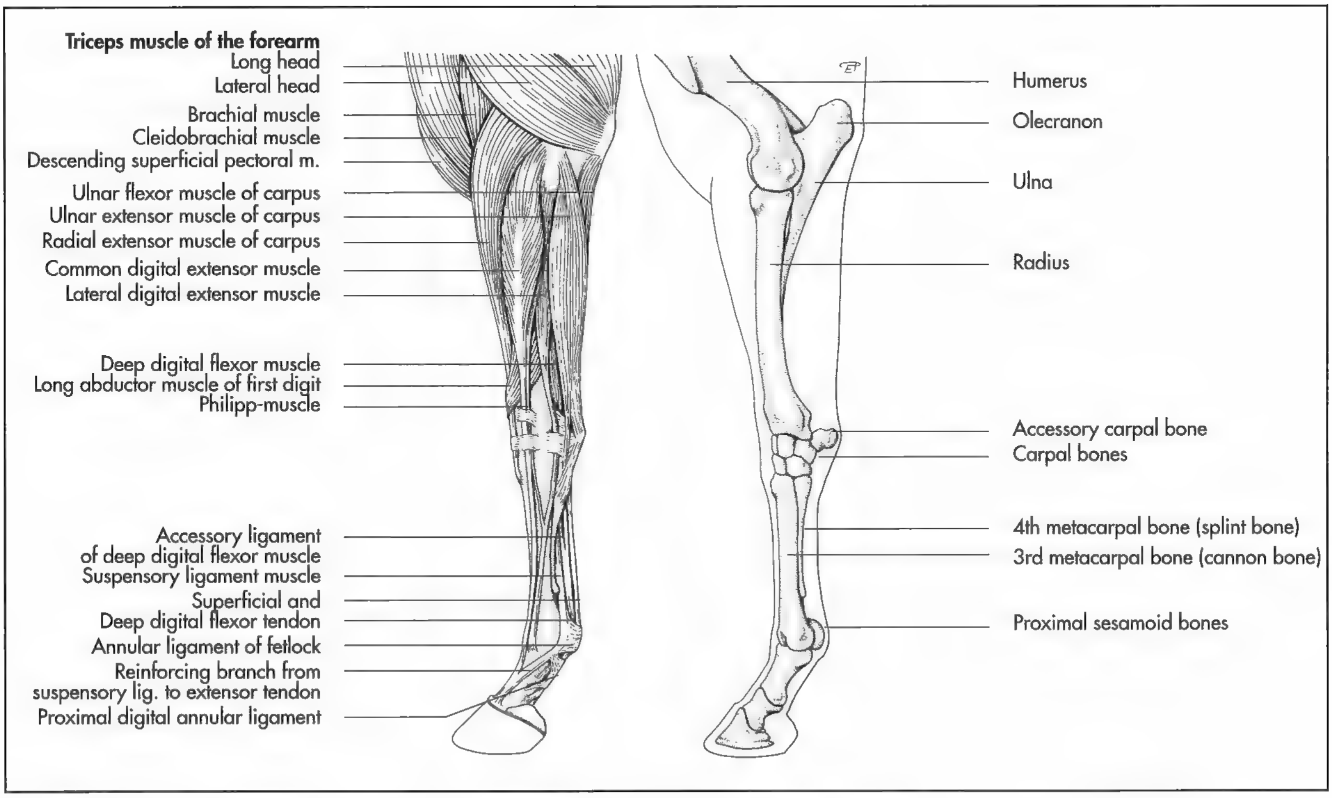

Fig. 3-83. Muscles and skeleton of the carpus and digit of the horse (schematic, lateral aspect).

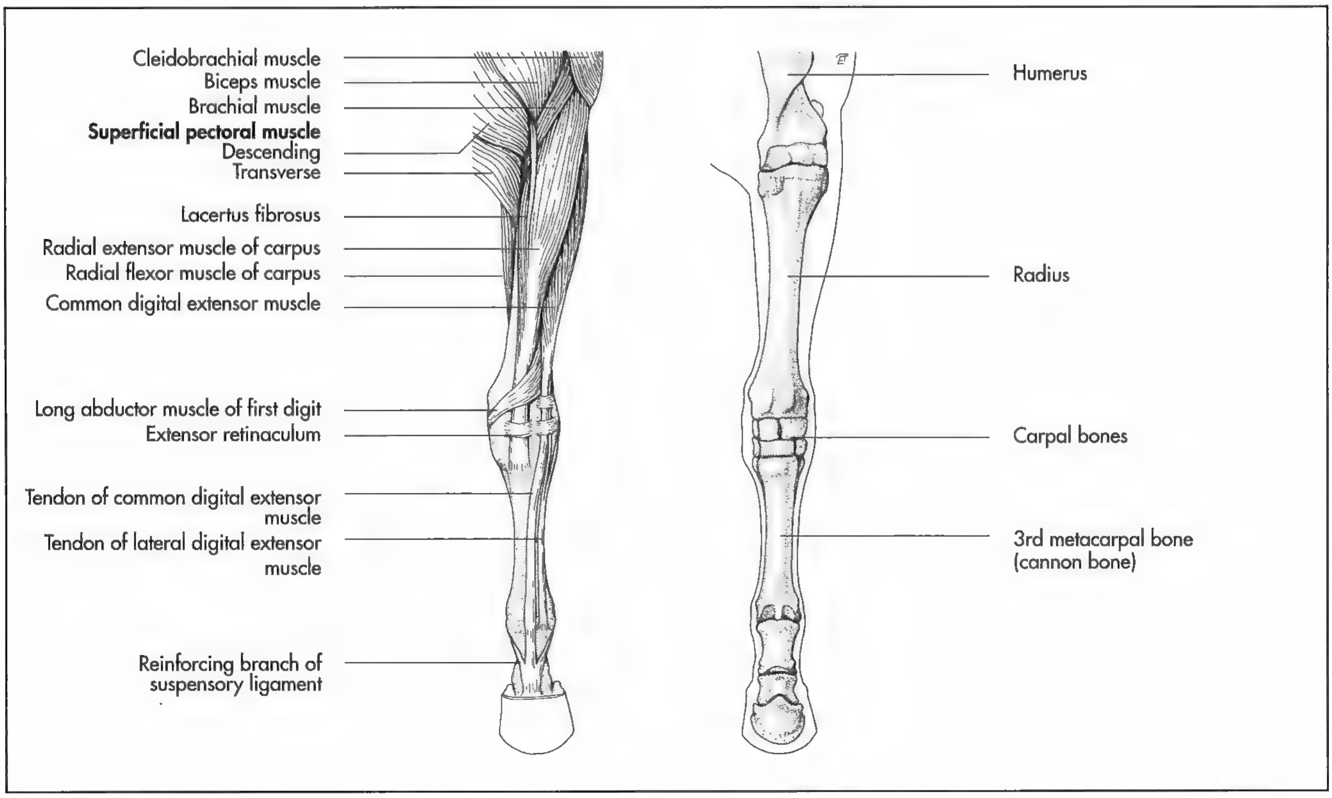

Fig. 3-84. Muscles and skeleton of the carpus and digit of the horse (schematic, dorsal aspect).

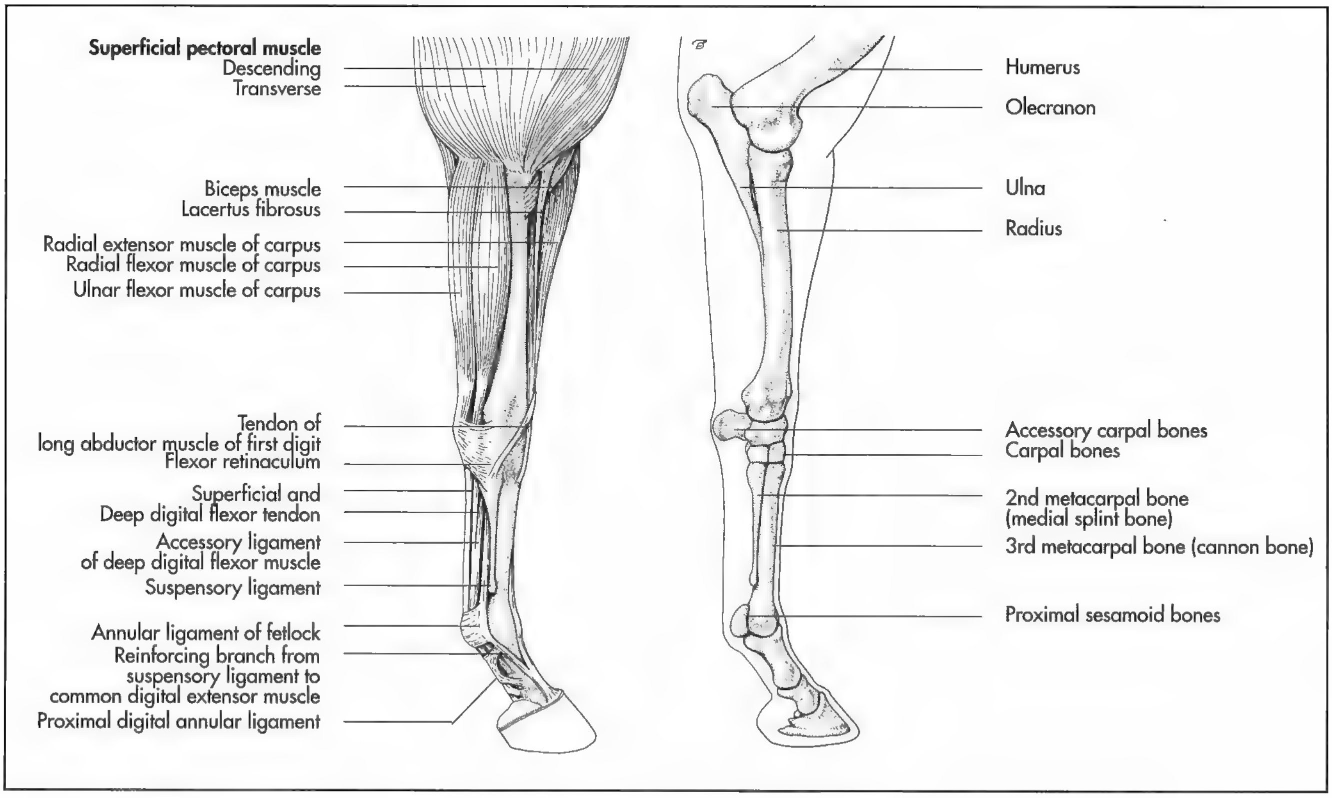

Fig. 3-85. Muscles and skeleton of the carpus and digit of the horse (schematic, medial aspect).

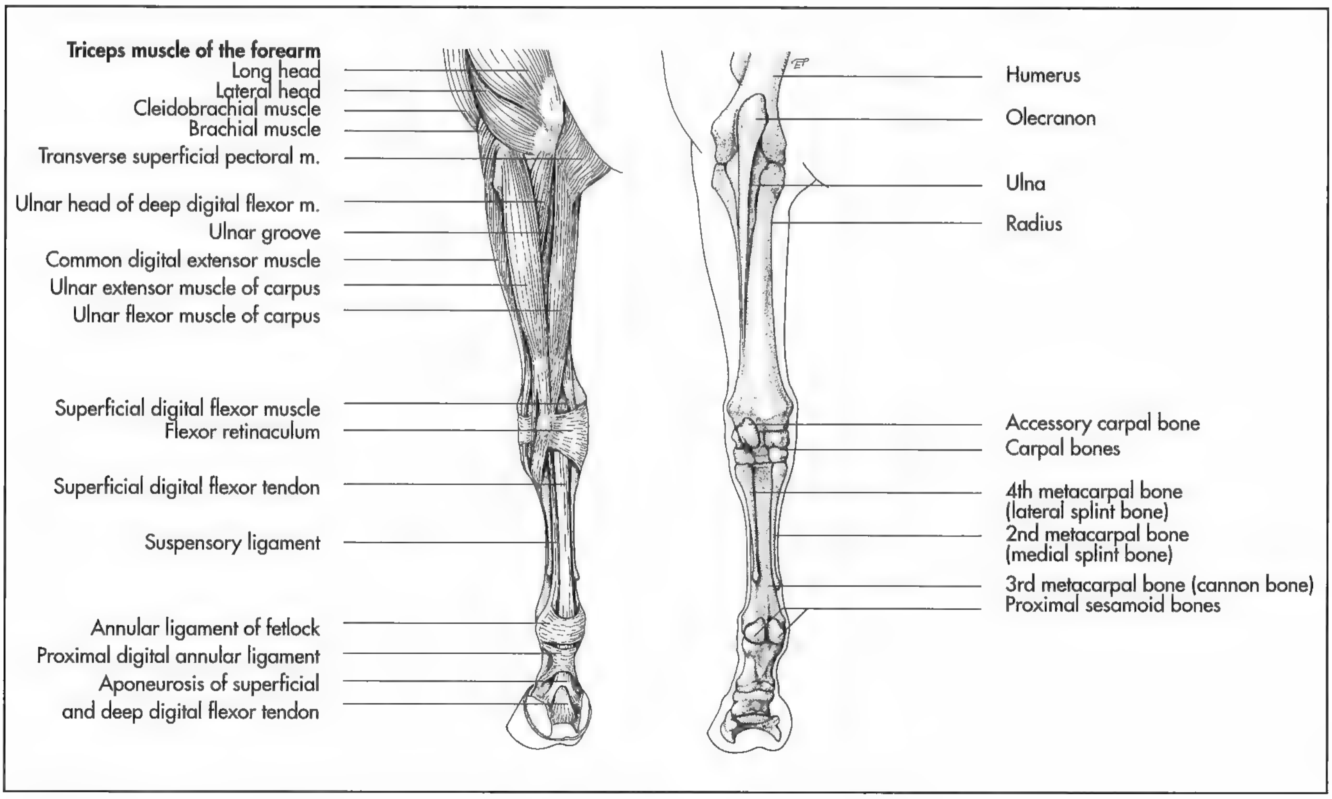

Fig. 3-86. Muscles and skeleton of the carpus and digit of the horse (schematic, palmar aspect).

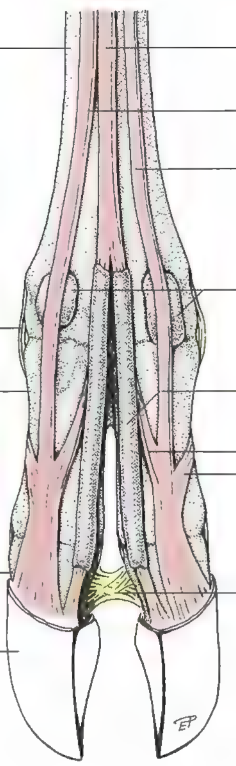

Fig. 3-87. Tendons and synovial structures of the left digit of the ox (schematic, dorsal aspect).

The proximal part of the superficial digital flexor muscle in ruminants is similar to the pig. It is divided into a superficial and deep belly. The superficial part passes over the flexor retinaculum, the deep part beneath it. Both tendons unite in the middle of the metacarpus to form a common tendon, which bifurcates into a medial and lateral branch further distally. Each branch unites with a band from the interosseous muscle and forms a ring for the corresponding branch of the deep digital flexor tendon near the metacarpophalangeal joint (Fig. 3-89). The stronger medial branch inserts on the flexor surface of the middle phalanx, the smaller lateral branch on the palmar aspect of the middle phalanx close to the articular surface. The tendons are enclosed in a common digital sheath at the metacarpophalangeal joint and held in place by the annular ligament of the fetlock (Fig. 3-88 and 89).

In the horse the superficial digital flexor muscle arises from the medial humeral epicondyle and covers the deep digital flexor muscle with which it is partly fused (Fig. 3-85 and 86). Its multipartate belly forms a strong tendon at the level of the carpus, where it combines with a strong fibrous band, the accessory ligament (also termed the radial or superior check ligament), which originates from the caudal radius. The tendon passes distally through the carpal canal to the palmar aspect of the metacarpus. It is enveloped by the carpal synovial sheath in common with the deep digital flexor tendon reaching from about 10 cm proximal to the carpus to the middle of the metacarpus (Fig. 3-82).

The superficial flexor tendon forms a tubelike enclosure around the deep digital flexor tendon just proximal to the metacarpophalangeal joint **(manica flexoria).** A second synovial sheath, the digital synovial sheath, partly encloses both tendons from the distal metacarpus to the middle of the middle phalanx. At the distal end of the proximal phalanx the superficial flexor tendon divides into branches through which the deep digital flexor tendon continues distally (Fig. 3-90 and 92). The two branches insert to the lateral and medial eminences on the proximal extremity of the middle phalanx and send also fibres to the lateral aspect of the proximal phalanx.

The superficial digital flexor tendon flexes the proximal and middle phalangeal joints of the main digits and thereby the whole foot. It also stabilises the fetlock joint.

The **deep digital flexor muscle** runs deep to the superficial digital flexor muscle and the flexor muscles of the carpus on the caudal side of the antebrachium (Fig. 3-83 to 86, 89 and 92). The deep digital flexor muscle arises with three heads, the **humeral head** (caput humeralis), the **radial head** (caput radiale) and the **ulnar head** (caput ulnare). The humeral head originates from the medial epicondyle of the humerus and consists of three bellies.

The resultant five bellies of the deepdigital flexor muscle fuse at the distal end of the forearm to form the deep digital flexor tendon. This tendon passes through the carpal canal medial to the accessory carpal bone and divides into a branch

Fig. 3-88. Acrylic cast of the digital synovial sheath of an ox (palmar aspect).

for each functional digit at the metacarpus, thus resulting in five tendons in carnivores, four tendons in the pig, two tendons in ruminants and one tendon in the horse. Each tendon of insertion passes through the corresponding branch of the superficial flexor tendon at the level of the proximal phalanx and continues to its insertion on the palmar aspect of the distal phalanx.

In carnivores the three heads of the muscle are completely separated. The humeral head consists of three isolated bellies in the cat, whereas in the dog the bellies are difficult to separate. It arises from the medial epicondyle of the humerus deep to the radial flexor muscle of the carpus (Fig. 3-77 to 81). The muscle is marked by multiple tendinous sheaths and bands and lies on the caudomedial side of the forearm, accompanied by the radial head on the medial side and the ulnar head laterally. The radial head arises on the caudomedial aspect of the proximal radius, the ulnar head from the caudal border of the ulna, extending from the olecranon to the distal third. The tendons converge to form the deep digital flexor tendon just proximal to the carpus. This tendon crosses the flexor side of the carpus in the carpal canal, covered by the flexor retinaculum. At the proximal end of the metacarpus the radial head splits away on the medial side to insert on the first digit. The principal tendon divides into four round branches which insert on the second to fourth digit at the metacarpus. At the level of the proximal sesamoid bones they pass through **tubular sheaths** (manica flexoria) formed by the branches of the superficial digital flexor tendon. They end on the flexor tuberosities of the distal phalanges of the second to fifth digit. The branches of the deep and superficial digital flexor tendon are held in place by three transverse ligaments:

- Annular palmar ligament, (ligamentum anulare palmare),
- Proximal digital annular ligament, (ligamentum anulare digitale proximale) and
- Distal digital annular ligament (ligamentum anulare digitale distale).

The **proximal ligament** lies at the level of the metacarpophalangeal joint, the **middle one** at the **middle of the first phalanx** and **the distal one** just distal to the proximal interphalangeal joint.

The distal branch inserting on the first digit has its own tendon sheath, extending from the metacarpus to its insertion. The branches of the main digits share their tendon sheaths with the corresponding branches of the superficial digital flexor tendon.

In ruminants, the humeral head shows numerous tendinous intersections and can be divided into three portions, which arise from the medial epicondyle of the humerus. It joins the radial and ulnar head to form the deep digital flexor tendon. After crossing the flexor side of the carpus it splits in-

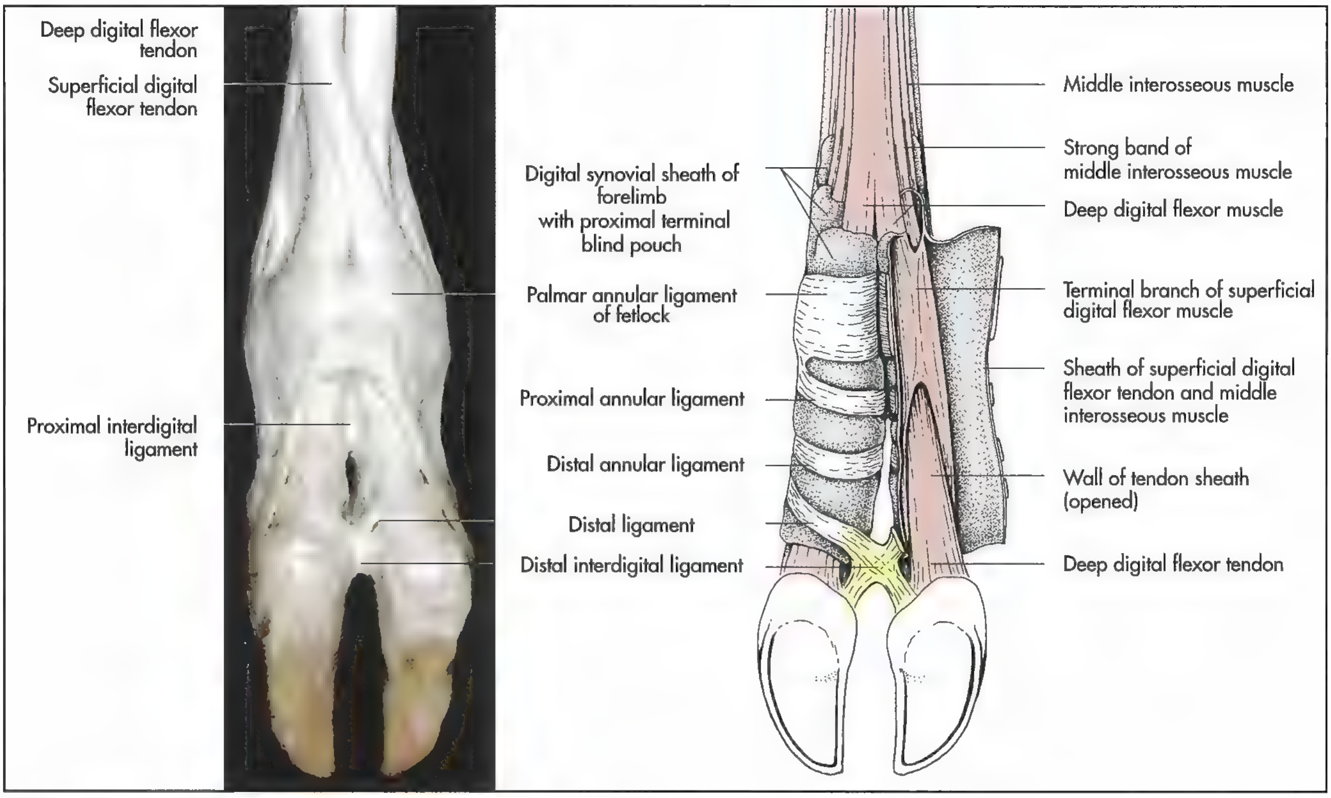

Fig. 3-89. Digital synovial sheath of the ox (schematic, palmar aspect).

to two tendons at the distal end of the metacarpus. At the level of the metacarpophalangeal joint the deep digital flexor tendon is flanked by the superficial flexor tendons and the middle interosseous muscle. The tendons of insertion pass over the distal sesamoid bones, where their passage is facilitated by the podotrochlear bursae and insert at the flexor tubercle of the distal phalanx of the third and fourth digit. Each branch of the deep digital flexor tendon is bound down by the proximal and distal annular ligament and the distal interdigital ligament.

A **synovial sheath** (vagina synovialis tendineum digitorum manus) surrounds the two flexor tendons of the third and fourth digit from the distal third of the metacarpus almost to the insertion (Fig 3-88 and 89). This digital sheath extends proximal and distal pouches. The proximal pouches extend between the branches of the interosseous muscle to the distal third of the metacarpus. The sheaths of the medial and lateral branch communicate through their proximal extensions. Several pouches extend distally between the annular ligaments and the two branches of the distal interdigital ligament to the distal phalanges. The sheath can be punctured from the lateral side on the dorsal border of the flexor tendons, about 2 cm proximal to the dewclaws. The needle is advanced in a horizontal plane and a lateromedial direction.

In the horse, the humeral head of the deep digital flexor tendon is marked by tendinous intersections and can be divided into three bellies, which arise together from the medial humeral epicondyle and continue distally on the caudal side of the radius before they fuse to form a common tendon just proximal to the carpus. The small radial head originates from the middle of the caudal surface of the radius and joins the principal tendon at the carpus. The ulnar head arises from the caudal aspect of the olecranon and runs distally as a small tendon between the flexor and ulnar extensor muscles of the carpus to the carpus, where it unites with the tendons of the other heads (Fig. 3-86). The conjoined tendon passes over the flexor side of the carpus through the carpal canal, enclosed in the carpal synovial sheath together with the superficial digital flexor tendon. It is enforced at about the middle of the metacarpus by a strong fibrous band, the **accessory** or **inferior check ligament** (ligamentum accessorium), which is a continuation of the palmar carpal ligament. At the fetlock it passes through the ring formed by the superficial digital flexor tendon **(manica flexoria)** and over the sesamoid groove (scutum proximale). In the middle of the proximal phalanx the deep digital flexor tendon emerges between the two branches of the superficial flexor tendon and passes over the flexor surface of the distal sesamoid bone to its insertion on the flexor surface of the distal phalanx.

The **navicular bursa** (bursa podotrochlearis) is interposed between the tendon and the distal sesamoid bone. It extends beyond the borders of this bone proximally, distally and laterally (Fig. 3-58 to 60 and 91).

The distal parts of the digital flexor tendons are held in place by annular ligaments, which are thickenings of the deep fascia (Fig. 3-90 to 92). It can be divided into:

Fig. 3-90. Acrylic cast of the digital synovial sheath of a horse (palmar aspect).

The **palmar annular ligament** is about 3 cm long, arises from the abaxial borders of the proximal sesamoid bones and is adherent to the superficial flexor tendon. Narrow bands of the palmar annular ligament extend distally on the medial and lateral side and unite with the proximal extensions of the proximal annular ligament.

The **proximal digital annular ligament** is arranged in a cruciate pattern and arises with two proximal branches from the medial and lateral aspect of the proximal phalanx and insert with two distal branches on the lateral and medial aspect of the distal end of the proximal phalanx. The middle part is firmly fused with the superficial digital flexor tendon.

The **distal digital annular ligament** covers the expanded tendon of insertion of the deep digital flexor tendon. It attaches proximally with two branches to the proximal phalanx together with the distal branches of the proximal digital annular ligament. Its superficial aspect is largely covered by the digital cushion and its deep surface is adherent to the deep digital flexor tendon, thus the distal digital annular ligament separates the digital cushion from the deep digital flexor tendon.

The digital flexor tendons are protected by two synovial sheaths: the **proximal carpal synovial sheath** (vagina synovialis communis musculorum flexorum) and the **distal digital synovial sheath** (vagina synovialis tendineum digitorum manus).

The **carpal synovial sheath** extends from a level 10 to 12 cm proximal to the carpus distal to the middle of the metacarpus, where the accessory ligament joins the deep digital flexor tendon. Synoviocentesis can be performed by inserting a needle at the proximal third of the metacarpus from the lateral side.

The **digital synovial sheath** begins at the distal end of the metacarpus, 5 to 8 cm proximal to the fetlock joint and extends to the middle of the second phalanx. In its larger part it enfolds the deep digital flexor tendon only, the superficial digital flexor tendon forming its palmar wall together with the deep fascia. Only in the region of the palmar annular ligament the deep digital flexor tendon is surrounded by palmar pouches of the digital synovial sheath.

The **palmar wall** follows the palmar aspect of the cannon bone proximally, passes over the sesamoid bones and the distal sesamoidean ligaments and follows distally on the palmar side of the middle phalanx. Although the sheath is adjacent to the metacarpophalangeal joint, distal interphalangeal joint and the navicular bursa, these cavities do not communicate.

The **digital synovial sheath** extends three paired proximal pouches and one distal pouch, where it is not covered by the annular ligaments (Fig. 3-90 and 91). One pair of the proximal pouches lies proximal to the palmar annular ligament palmar to the branches of the interosseous muscle, the second pair lies between the palmar annular ligament and the proxi-

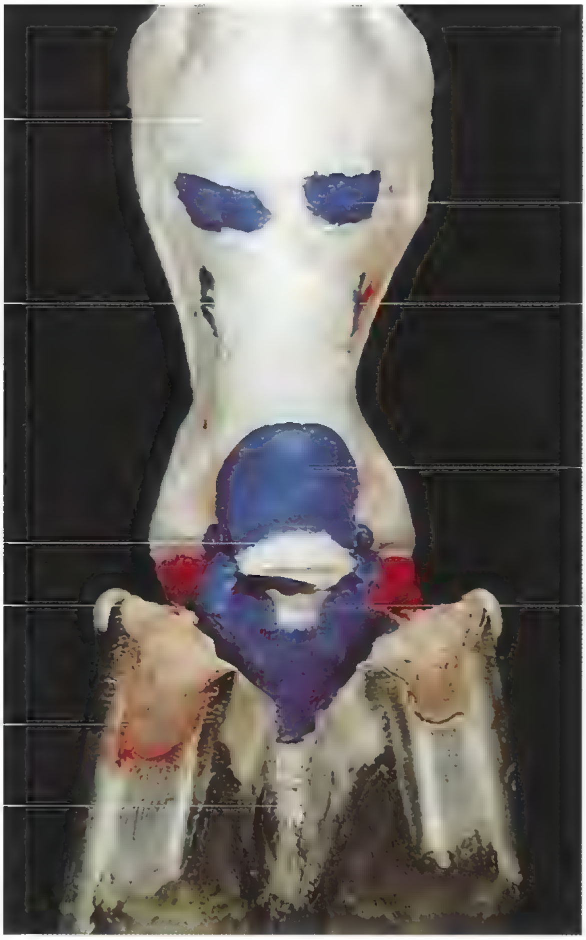

Fig. 3-91. Acrylic cast of the digital synovial sheath and the navicular bursa of a horse (palmar aspect) (courtesy of Prof. Dr. Sabine Breit, Vienna).

mal digital annular ligament and the third proximal pair between the proximal and distal branches of the proximal digital annular ligament. The distal pouch is found between the distal branches of the palmar digital annular ligament and the proximal border of the distal digital annular ligament. When distended in cases of inflammation they bulge out noticably. The digital sheath can be punctured about 3 cm proximal to the proximal sesamoid bones between the interosseous muscle and the deep digital flexor tendon.

The deep digital flexor tendon flexes the distal phalanx of the main digits and thereby the whole foot.

The **interflexor muscles** are small muscles or tendons lying between the deep and superficial digital flexor muscles. They are thought to assist these muscles. Whereas in ruminants and the pig there are proximal and distal interflexor muscles, only a distal interflexor muscle exists in carnivores and they are altogether absent in the horse.

In carnivores, the distal interflexor muscle arises from the humeral head of the deep digital flexor muscle at the distal quarter of the antebrachium. It passes with one tendon in the dog and with two or three tendons in the cat over the flexor side of the carpus between the flexor tendons. It further splits into three branches at the metacarpus, which insert with the corresponding branches of the superficial digital flexor tendon on the second to fourth digit.

In the pig, the interflexor muscles have two or three bellies, which join the two flexor tendons distally.

In ruminants, the bellies of the interflexor muscle run distally beteen the digital flexors and radiate into the tendons of insertion of the superficial digital flexor muscle.

Short digital muscles

The short digital muscles show marked species differences in number, structure and function. In carnivores and the pig they assist in the movement of the single digits, whereas in large animals they are an important part of the passive stay apparatus.

The short digital muscles comprise:

- Interosseous muscles (mm. interossei),
- Lumbrical muscles (mm. lumbricales) and
- Short digital flexor muscle (m. flexor digitorum brevis).

The **interosseous muscles** lie directly on the palmar side of the metacarpus. They originate from the proximal end of the

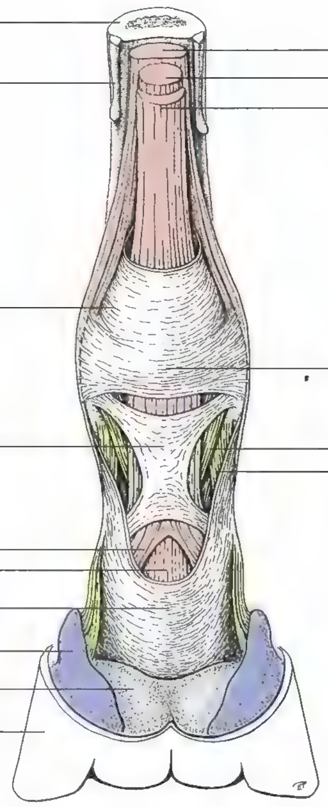

Fig. 3-92. Fasciae of the distal forelimb in the horse (schematic, palmar aspect).

metacarpal bones and the joint capsule of the carpus and insert on the proximal sesamoid bones. They are fleshy muscles in the carnivores and pig and tendinous in the adult ruminant and the horse.

In carnivores there are four interosseous muscles. They arise from the proximal ends of the second to fifth carpal bones and cover the entire palmar surface of these bones. Each muscle divides into two branches, that attach to the proximal sesamoid bones. A portion of each tendon joins the corresponding branch of the common digital extensor muscle.

In ruminants the interosseous muscle has a single origin, but divides into five branches at the distal metacarpus. The abaxial branches attach to the proximal sesamoid bones of the main digits, while the middle branch passes through the intertrochlear notch at the distal extremity of the metacarpus and bifurcates, each branch fusing with the corresponding extensor tendon.

There are three interosseous muscles in the horse. The medial and lateral interosseous muscles are very small muscles and of no functional importance. The **middle interosseous muscle** is also termed the **suspensory ligament.** It is a strong tendinous band, which arises from the proximal end of the cannon bone and the distal row of the carpal bones. It lies in the metacarpal groove between the splint bones, deep to the flexor tendons and divides into two diverging branches, which insert on the proximal sesamoid bones. Each branch extends a band medially and laterally, to the common digital extensor tendon. The primary function of the suspensory ligament to provide the proximal support of the fetlock. Its functional continuation distal to the sesamoid bones is provided by the cruciate, oblique and straight sesamoidean ligaments.

This **stay apparatus** prevents excessive dorsal flexion of the fetlock, it also limits palmar flexion by means of the extensor branches to the common digital extensor tendon and diminishes concussion.

The **lumbrical muscles** are small muscles, which lie on the palmar aspect of the metacarpus between the digital flexors. They are not present in ruminants. There are three lumbrical muscles in carnivores, which arise from the branches of the deep digital flexor tendon and insert to the proximal phalanx of the second to fifth digit. In the horse they are very slender muscles, which lie on either side of the digital flexor tendons proximal to the fetlock. They arise from the deep digital flexor tendon and radiate into the tissue supporting the ergot. They assist the digital flexor tendons and support the ergot in the horse.

Fig. 3-93. Recesses of the synovial sheath of the flexor tendons in a horse (dorsolateral aspect).

The **short digital flexor muscle** exists only in carnivores. It is a delicate muscle, which arises from the superficial digital flexor tendon at the level of the carpus and ends on the transverse ligament of the metacarpophalangeal joint of the fifth digit.

Special muscles of the digits of carnivores

In carnivores a number of small digital muscles assist in the extension, flexion, abduction, adduction and rotation of the digits. They are well developed in the cat and are important for the coordination of the movement of the paw. It is beyond this book to describe them in detail.

4 Hindlimb or pelvic limb (membra pelvina)

H.-G. Liebich, H. E. König and J. Maierl

Skeleton of the pelvic limb (ossa membri pelvini)

Pelvic girdle (cingulum membri pelvini)

The pelvic girdle consists of two symmetrical **hip bones (ossa coxae),** which meet ventrally at the **pelvic symphysis (symphysis pelvina)** and articulate firmly with the sacrum dorsally. Together with the **sacrum** and the **first caudal vertebrae,** they form the **bony pelvis,** encircling the pelvic cavity (Fig. 4-1). The pelvis fulfils several different functions, requiring a dynamic anatomical construction. It encompasses and protects the pelvic viscera including the reproductive organs, which in turn exert physiological influence during pregnancy and parturition. It also has an essential role in posture and locomotion, in that it ensures an effective transmission of forces from the hindlimbs to the trunk.

Each **hip bone** is composed of three parts with separate ossification centres. In juvenile animals the single bones are demarcated by cartilaginous borders, which allow for growth. In the adult the bones are completely fused and their bodies form the cavity for the articulation with the femur, the acetabulum. Each hip bone is composed of:

- Ilium (os ilium),
- Pubis (os pubis) and
- Ischium (os ischii).

The pubis and ischium of each hip unite ventrally in the cartilagenous **pelvic symphysis (symphysis pelvina),** which is a firm but non-rigid joint allowing the two halves to move apart under hormonal influence to enlarge the birth canal in preparation for parturition. The symphysis can be divided into a cranial **pubic part** (symphysis pubica) and a caudal **ischial part** (symphysis ischiadica).

The three components of a hip bone will be described separately out of didactic reasons.

Ilium (os ilium)

The ilium forms the dorsocranial part of the hip bone and extends obliquely from the acetabulum to the sacrum (Fig. 4-1 to 8). It can be divided into the cranial expanded **wing** (ala ossis ischii) and the columnar **body** (corpus ossis ilii) caudally. The body of the ilium contributes to the formation of the **acetabulum,** which is completed by the bodies of the ischium and pubis. The orientation of the **ileal wings** is species specific, significantly influencing the form of the pelvis. In the horse and the ox they are orientated vertically, whereas in the small ruminants they are rotated dorsolaterally and in the pig and carnivores they are almost sagittal. Various marked prominences, crests and notches give the wing of the ilium a characteristic appearance (Fig. 4-5 and 6).

An important landmark in all domestic mammals is the **coxal tuberosity** (tuber coxae) at the lateral angle of the hip, which forms the point of the hip visible in the horse and ox and palpable in the dog. In carnivores the coxal tuberosity has two prominences, the **cranial** and **caudal ventral iliac spines** (spinae iliacae ventrales craniales et caudales). The mediodorsal angle of the ilial wing is thickened forming the **sacral tuber** (tuber sacrale). In carnivores and cattle the sacral tuber also has two eminences, the cranial and caudal dorsal iliac spines (spinae iliacae ventrales craniales et caudales). The **iliac crest** (crista iliaca) connects the coxal tuberosity and sacral tuber. It is convex and thick in carnivores and in the pig, thin and concave in large animals (Fig. 4-7 and 8).

The ilium presents a **lateral** (dorsolateral) or **gluteal surface** (facies glutea) and a **medial (medioventral) surface** (facies sacropelvina). The concave lateral surface is crossed by three **gluteal lines** (lineae gluteae) in carnivores and one gluteal line in the rest of the domestic mammals giving origin to the gluteal muscles.

The medial surface is divided into two parts. The lateroventral part of the **medial surface** (facies iliaca) gives rise to the insertions of several pelvic muscles. The mediodorsal part of the medial surface is formed by the roughened **auricular portion** (facies auricularis) and the **iliac tuberosity** (tuberositas iliaca), which articulate with the sacrum to form the **tight sacroiliac joint.**

The dorsomedial border of the iliac wing is deeply concave to form the **greater sciatic notch** (incisura ischiadica major) at the junction with the iliac body over which the sciatic nerve runs. The ventral border of the body of the ilium is marked by the **arcuate line** (linea arcuata), which carries the psoas tubercle for the attachment of the smaller psoas muscle.

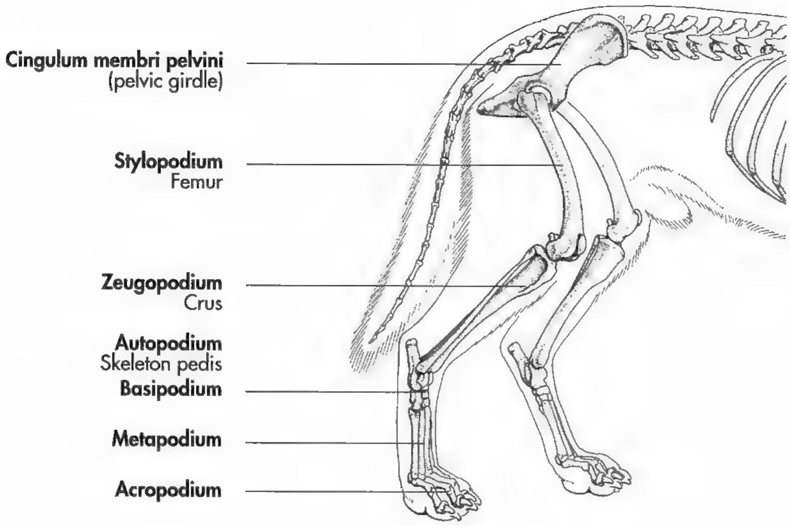

Fig. 4-1. Skeleton of the pelvic limb of the dog: Parts (schematic).

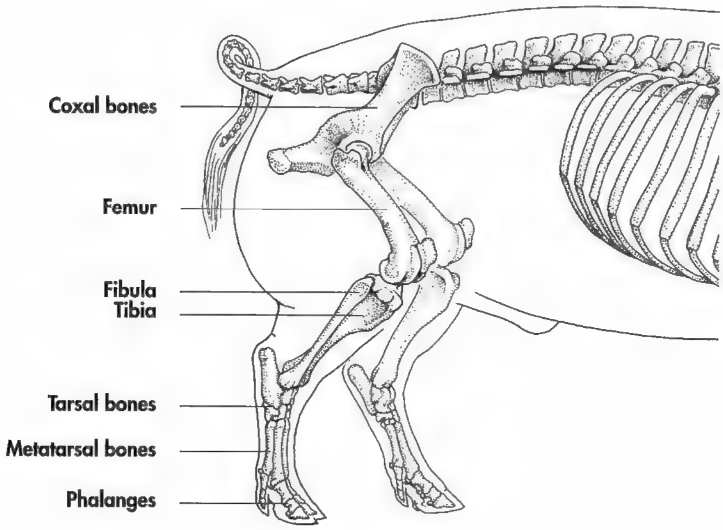

Fig. 4-2. Skeleton of the pelvic limb of the pig: Terms of the bones (schematic).

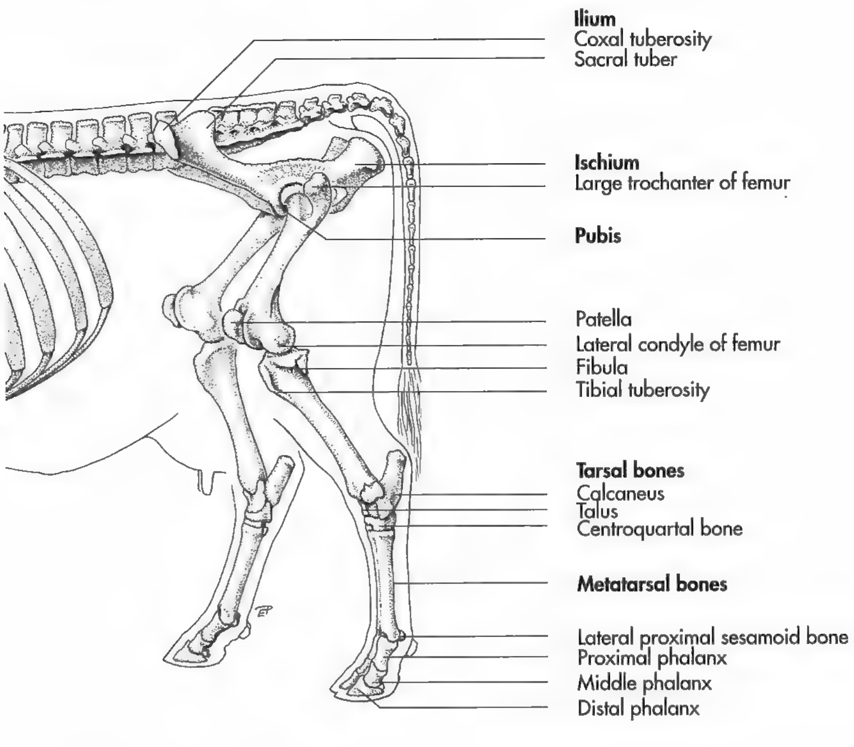

Fig. 4-3. Skeleton of the pelvic limb of the cow: Osseous structures (schematic).

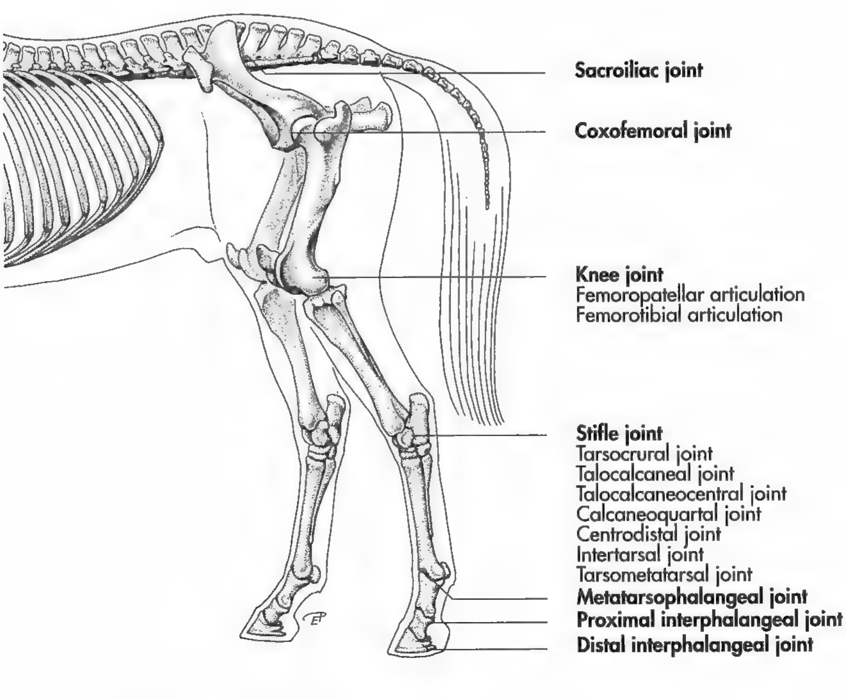

Fig. 4-4. Skeleton of the pelvic limb of the horse: Joints (schematic).

Fig. 4-5. Hip bones (ossa coxae) of a pig (dorsal aspect).

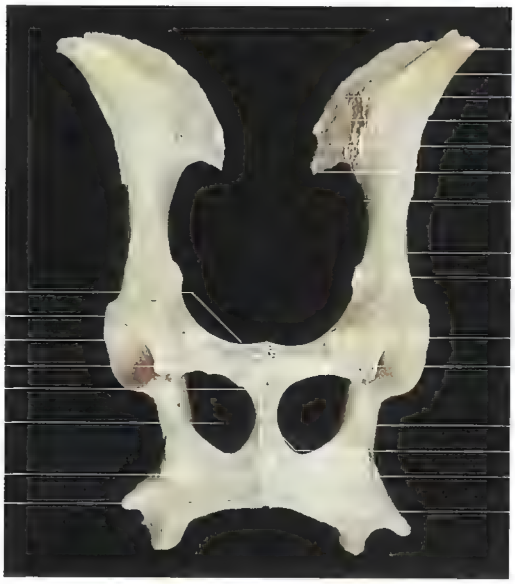

Fig. 4-6. Hip bones (ossa coxae) of a pig (ventral aspect).

Pubis (os pubis)

The pubis is L-shaped and consists of the **body** (corpus ossis pubis), the transverse **acetabular branch** (ramus cranialis ossis pubis) and the sagittal **symphysial branch** (ramus caudalis ossis pubis) (Fig. 4-5 to 8). The pubis borders more than half of the **obturator foramen** (foramen obturatum), a large opening in the pelvic floor through which the **obturator nerve** (nervus obturatorius) passes. It is closed by musculature and soft tissue. The cranial edge of the acetabular branch is termed **pecten of the pubis** (pecten ossis pubis) and forms the **iliopubic eminence** (eminentia iliopubica) for the attachment of abdominal muscles. In the horse the ventral surface of the iliopubic eminence is crossed by the **pubic groove** (sulcus ligamenti accessorii ossis femoris) leading to the acetabulum, through which the accessory ligament of the headof the femur passes. The pubis of each side fuses in the **pubic symphysis** (symphysis pubica), the cranial part of the **pelvic symphysis** (symphysis pelvina). On the ventral surface of the pubic symphysis protrudes the **ventral pubic tubercle** (tuberculum pubicum ventrale). In the stallion also a dorsal pubic tubercle exists.

Ischium (os ischii)

The ischium can be divided into the **body** (corpus ossis ischii), the **caudal plate** (tabula ossis ischii) and the **medial branch** (ramus ossis ischii) (Fig. 4-5 to 8). The caudal plate

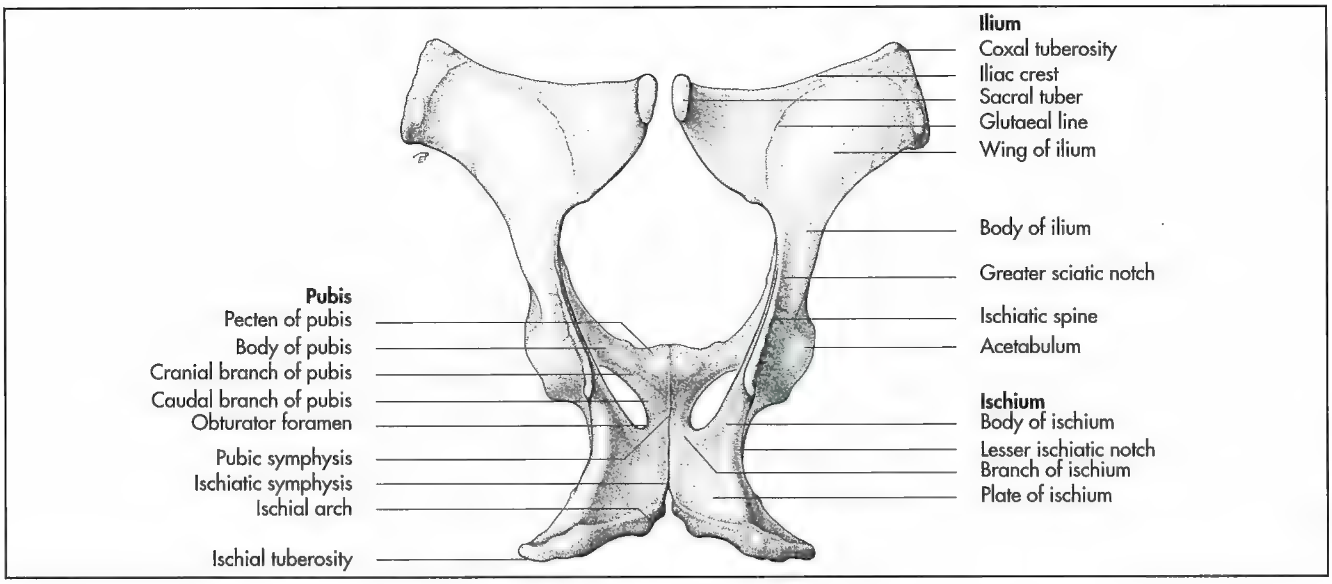

Fig. 4-7. Hip bones (ossa coxae) of the horse (schematic, dorsal aspect).

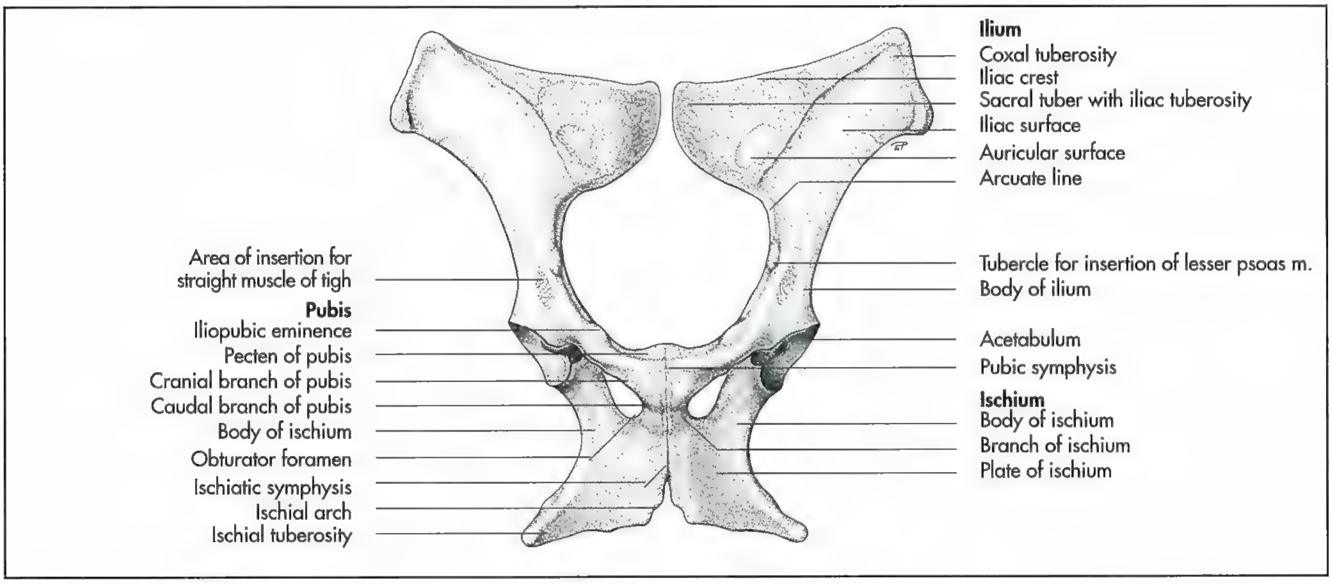

Fig. 4-8. Hip bones (ossa coxae) of the horse (schematic, ventral aspect).

extends cranially into two branches, a symphysial branch and an acetabular branch, which form the caudal circumference of the obturator foramen. The medial branches of the ischia form the caudal part (symphysis ischiadica) of the pelvic symphysis. The **body of the ischium** (corpus ossis ischii) forms part of the acetabulum, while its dorsal border continues with the dorsal border of the ilium to form the **ischiatic spine** (spina ischiadica). The ischiatic spine tapers towards the lesser **sciatic notch** (incisura ischiadica minor), the indented border between the **ischial tuberosity** (tuber ischiadicum) and the caudal rim of the acetabulum.

The caudolateral part of the caudal ischiatic plate is thickened to form the **ischial tuberosity** (tuber ischiadicum), which is a linear thickening in the dog and horse and a triangular shaped eminence in the ox and pig. The ischial tuberosity is a visible landmark in most domestic mammals.

The caudal borders of the ischiatic tables meet in the concave **ischial arch** (arcus ischiadicus). This notch is usually broad and deep, except in the horse where it is rather shallow and irregular.

Acetabulum

The acetabulum is a deep cotyloid cavity to which all three pelvic bones contribute (Fig. 4-5 to 16). An additional fourth bone in the centre of the cavity, the **small acetabular bone** (os acetabuli) is present in carnivores. It is composed of the body of the ilium craniolaterally, the body of the ischium

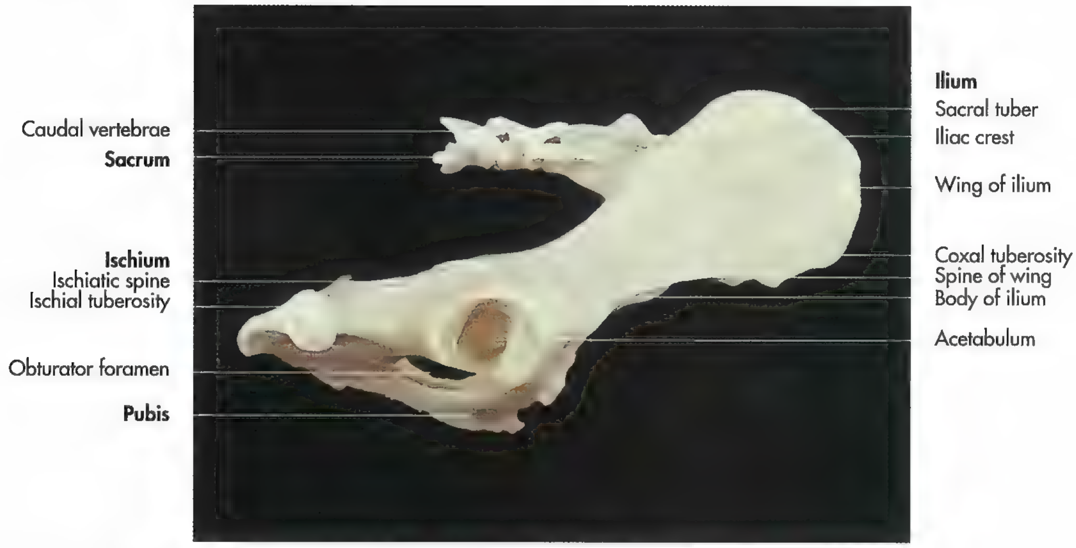

Fig. 4-9. Hip bones (ossa coxae), sacrum and caudal vertebrae of a dog (left lateral aspect).

Fig. 4-10. Os coxae, sacrum and caudal vertebrae of a dog, paramedian section of the left hip bone (medial aspect).

caudolaterally and the body of the pubis medially. The acetabulum is reciprocal to the head of the femur with which it forms a spheroidal joint, the hip joint. The cavity of the acetabulum consists of the peripheral **articular lunate surface** (facies lunata) and the non-articular acetabular fossa (fossa acetabuli) in the centre. The lunate surface is crescentic and indented medially by the deep acetabular notch (incisura acetabuli). The articular surface is enlarged by an fibrocartilagenous **articular labrum** (labrum acetabulare). The **intracapsular ligament of the femoral head** (ligamentum capitis ossis femoris) emerges through the acetabular notch and joins the femoral head to the acetabular fossa. In the horse a second (accessory) ligament inserts at the acetabular fossa.

The lunate surface of the ox is divided by a cranioventral notch into a larger craniodorsal (pars major) and smaller caudoventral part (pars minor).

Pelvis

The **bony pelvis** is a broad ring around the pelvic cavity. Its conformation reflects the multiple functions the pelvis has to fulfil. Species-specific differences in the general form of the pelvis are very pronounced. It gives attachment to a multitude of muscles, tendons and ligaments and its surfaces are modelled accordingly. Its roof is formed by the sacrum and the first few caudal vertebrae, its floor (solum pelvis osseum) by the pubic and ischial bones and its lateral walls by the ilia and ischia. The broad sacrotuberous ligaments closes the bony defect in the lateral wall in all domestic mammals, except the carnivores. The **cranial pelvic aperture** or **inlet** (apertura pelvis cranialis) is bounded by the terminal line (linea terminalis). The terminal line passes along the promontory of the sacrum dorsally, the wings of the ilia laterally and ends in

Fig. 4-11. Left acetabulum of an ox (lateral aspect).

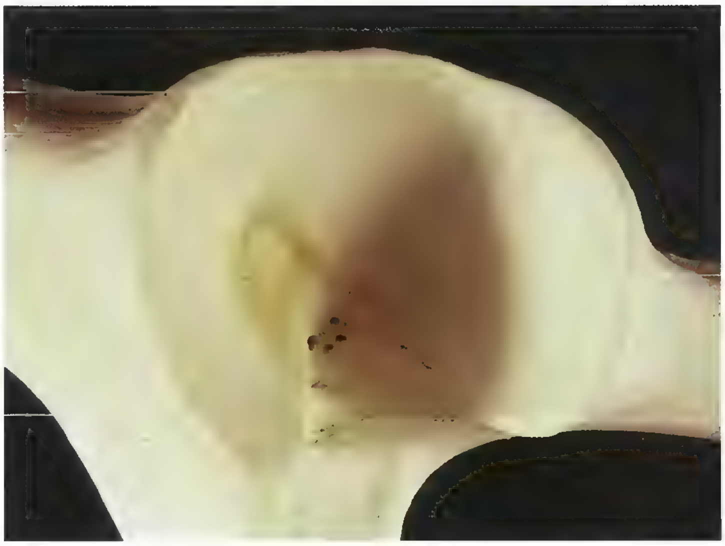

Fig. 4-12. Left acetabulum of a horse (lateral aspect).

the pecten of the pubis ventrally. It is almost circular in female animals and more egg-shaped in male animals, with the apex facing ventrally.

The **caudal pelvic aperture** or **outlet** (apertura pelvis caudalis) is formed by the first three or four caudal vertebrae dorsally, the ischiatic arch and the ischial tuberosities ventrally and the broad sacrotuberous ligament laterally. The sacrotuberous ligament is string-shaped in dogs and is absent in the cat.

The **floor of the pelvis** (solum pelvis osseum) is of considerable obstetric importance. In ruminants the pelvic floor is deeply concave, particularly in the transverse direction and inclined dorsally in the caudal part, in carnivores the floor is also concave, but shallower and in the horse it is flat and vertical. Several diameters of the pelvic cavity can be defined extending between osseous landmarks of the pelvis. The following measurements of the pelvic cavity are used in obstetrics:

- **Pelvic axis** (axis pelvis): The imaginary line drawn in a cranial to caudal direction through the middle of all lines between the sacrum and the pelvic symphysis.
- **Conjugate diameter** (diameter conjugata): Distance from the sacral promontory to the cranial border of the pelvic symphysis. It measures the diameter of the pelvic inlet.
- **Diagonal conjugate diameter** (conjugata diagonalis): Distance from the sacral promontory to the caudal border of the pelvic symphysis.
- **Vertical diameter** (diameter verticalis): Diameter between the sacrum or caudal vertebra and the cranial border of the pelvic symphysis, orthogonal to the pelvic symphysis.

Fig. 4-13. Hip bones (ossa coxae) and sacrum of a horse (left lateral aspect).

Fig. 4-14. Hip bones (ossa coxae) and sacrum of a horse (ventrocranial aspect).

- The last diameter measures the **diameter of the pelvic cavity** in a dorsoventral direction andis of considerable practical importance. In ruminants, horses and in the adult pig the vertical diameter extends between the sacrum andthe pelvic symphysis, which makes an expansion of the pelvis impossible. In carnivores the sacrum is very short and the vertical diameter extends between the caudal vertebrae and the pelvic symphysis.

In these animals and in the juvenile pig, in which the sacral vertebrae are not yet fused, some enlargement of the birth canal is possible. The angle between the vertical and conjugated diameter measures the **inclination of the pelvis** (inclinatio pelvis). The **transverse diameter** (diameter transversa) is defined as the maximum transverse measurement of the terminal line. Other transverse measurements are the diameter between the middle of the **ischial spine of each side** (diameter spinatransversa) and the distance between the **ischial tuberosities** (diameter transversa tuber ischiadici).

Pelvic cavity

Species specific differences in the form of the pelvic cavity are very pronounced and the dimensions of the pelvic cavity are of considerable obstetric importance (Fig. 4-5, 10 and 17).

In the dog the pelvic inlet is very oblique with the pecten of the pubis level with or behind the sacrum. The iliac bodies are

Fig. 4-15. Hip bones (ossa coxae) and sacrum of an ox (left lateral aspect).

Fig. 4-16. Hip bones (ossa coxae) and sacrum of an ox (ventrocranial aspect).

not parallel, the pelvic inlet is widest in its middle and narrowest dorsally. The pelvic outlet is rather wide and can be enlarged by elevating the tail. The pelvic cavity as a whole is straight and short and causes few problems during parturition in the dog.

In the pig the sacrum is slightly bent and the pelvic floor is flattened and has a ventral inclination caudally. The pelvic inlet is very oblique and almost in the dorsal plane, resulting in a long conjugate diameter. The diameter between the ischiadic spines is narrowed by their inward orientation. The bony birth canal, therefore, measures about 8 to 9 cm in all directions. Despite thick layers of fat and muscles the coxal tuberosity and ischial tuberosity are still palpable. The ischial tuberosity remains isolated from the rest of the skeleton for years, which can cause clinical problems.

In the ox, the pelvic roof narrows from cranial to caudal (Fig. 4-15). The sacrum, which contributes most to the pelvic roof, is concave throughout its length. The lateral wall is formed by the ilial wings cranially and the pronounced ischiatic spine further caudally. The oblique orientation of the pelvic inlet places the pecten of the pubis beneath the second intersacral joint, which causes the pelvic inlet to be comparatively narrow. The rigidity of the sacrum makes an enlargement of the vertical diameter impossible. The pelvic outlet is narrower than the inlet. The diameter of the birth canal is diminished by the inward deviation of the ischial spines and the ischial tuberosities, which project dorsally from the pelvic floor. Another complicating factor regarding the passage of the foetus during parturition is the broken axis of the birth canal.

Fig. 4-17. Radiograph of the pelvic region of a dog (ventrodorsal projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Tab. 4-1. Times of appearance and fusion of the separate ossification centres of the pelvis (Ghetie, 1971).

Species	Primary ossification centres				Additional ossification centres (iliac crest, iliac spine ventrocranial, ischial tuberosity, border of the epiphysis of the ischium)		
	Appearance			Fusion	Appearance		Fusion
	Ilium	Ischium	Pubis		Ilium	Ischium	
Horse	2nd month of pregnancy	3rd month of pregnancy	5th –6th. month of pregnancy	10–12 months after birth	6–8 months after birth	3–5 months after birth	4½ – 5 years
Ox	2nd month of pregnancy	3rd month of pregnancy	4th –5th month pregnancy	7–10 months after birth	6–8 months after birth	3–5 months after birth	5 years
Pig	7th week of pregnancy	2nd month of pregnancy	2nd month of pregnancy	1st year after birth	6–8 months after birth	3–5 months after birth	6–7 years
Dog	4th week of pregnancy	5th week of pregnancy	5th week of pregnancy	6 months after birth	4–6 months after birth	4–6 months birth	1½ – 2 years
Cat	4th week of pregnancy	5th week of pregnancy	5th week of pregnancy	6 months after birth	4–6 months after birth	4–6 months after birth	

Fig. 4-18. Proximal extremity of the left femur of a dog (cranial aspect).

Fig. 4-19. Proximal extremity of the left femur of a dog (caudal aspect).

In the horse the pelvic roof is formed by the sacrum and the first two caudal vertebrae and slopes slightly downward caudally. Compared to pigs and cattle the ischiatic spine and tuberosity are less pronounced and therefore the sacrosciatic ligament contributes a greater part to the lateral wall of the pelvic cavity (Fig. 4-13). The pelvic floor is vertical and flattened. Young horses show a swelling in the median of the pubis, which disappears in adult mares. The terminal line strikes the pecten of the pubis at the level of the third or fourth sacral vertebra in the mare and the second sacral vertebra in the stallion. The pelvic inlet is wide and circular in the mare and more angular, especially ventrally in the stallion. The pelvic cavity of the mare is more favorably formed for giving birth than that of the cow. The inlet is wide, the outlet not diminished by osseous protuberances, the axis straight and the cavity as a whole more spacious.

The appearance and fusion of the separate ossification centres of the coxal bones are shown in table 4-1.

Skeleton of the thigh (skeleton femoris)

The skeleton of the proximal part (stylopodium) of the free appendage of the hindlimb is formed by a single bone, the **femur** (os femoris) (Fig. 4-1 to 4). The femur is the strongest of the long bones. Up to **four sesamoid bones** can be found located in the soft tissues of the thigh. The largest sesamoid bone is the **patella** or kneecap, which is embedded in the tendon of insertion of the quadriceps muscle of the thigh. In carnivores two additional sesamoid bones are embedded in the heads of the gastrocnemius muscle and one in the head of the popliteal muscle.

The **femur** has a central function for posture and locomotion. Its surface is characteristically modelled, similar to the humerus, by the origin and attachment of strong muscles and their tendons, prominent bony protuberances and grooves (Fig. 4-20 to 22). In spite of species specific modifications the femur can be divided into three basic segments:

- Proximal extremity carrying the head (caput ossis femoris),
- Shaft of femur (corpus ossis femoris),
- Distal extremity bearing the medial and lateral condyle (condylus lateralis et medialis).

The **proximal extremity** curves medially and bears the prominent **femoral head,** which is offset from the long axis of the bone. The femoral head has a hemispherical articular surface for the articulation with the acetabulum, which is interrupted by a **notch** (fovea capitis) in which the intracapsular ligament of the femoral head (ligamentum capitis ossis femoris) attaches. This notch is circular and located in the centre in the dog and wedge-shaped and open to the periphery medially in the horse. The femoral head is separated from the shaft of the femur by a distinct **neck** (collum ossis femoris) in carnivores and in the pig. Lateral to the head projects a large process, the **greater trochanter** (trochanter major), which extends beyond the dorsal limit of the head of the femur in large animals, but stays level with the head in small animals and in the pig. The greater trochanter gives attachment to the gluteal muscles, acting as a lever arm for these extensors of the hip joint.

The greater trochanter and the neck of the femur are separated by the **trochanteric fossa** (fossa trochanterica) in which the deep muscles of the hip insert. It is divided into a cranial and a caudal part (pars cranialis et caudalis) in the horse. A smaller process, the **lesser trochanter** (trochanter minor) is present on the medial side and provides attachment to the iliopsoas muscle. In the horse, an additional process, the **third trochanter** (trochanter tertius) is located on the lateral aspect of the proximal third of the shaft and gives insertion to the superficial gluteal muscle.

The **diaphysis** is formed by the **shaft.** Its caudal surface is marked by a roughened area proximally (facies aspera), which is framed by the medial and **lateral lips** (labium mediale et laterale) to which the adductor muscles attach. These

Fig. 4-20. Distal extremity of the left femur of a dog (cranial aspect).

Fig. 4-21. Distal extremity of the left femur of a dog (caudal aspect).

lips continue distally and enclose the **popliteal surface** (facies poplitea). In the horse the caudodistal aspect is hollowed by the **supracondylar fossa** (fossa supracondylaris), which increases the area of origin of the superficial digital flexor muscle. The lateral and medial supracondylar tuberosities which give origin to the gastrocnemius muscle are situated on the distal third of the shaft.

The **distal extremity** carries **medial** and **lateral condyles** (condylus lateralis et medialis) caudally and a trochlea cranially (Fig. 4-23, 24, 26 and 28). The condyles articulate with the proximal end of the tibia and the menisci to form the **femorotibial joint** (articulatio femorotibialis). Between the medial and lateral condyle is the deep **intercondylar fossa** (fossa intercondylaris), which is separated from the **popliteal**

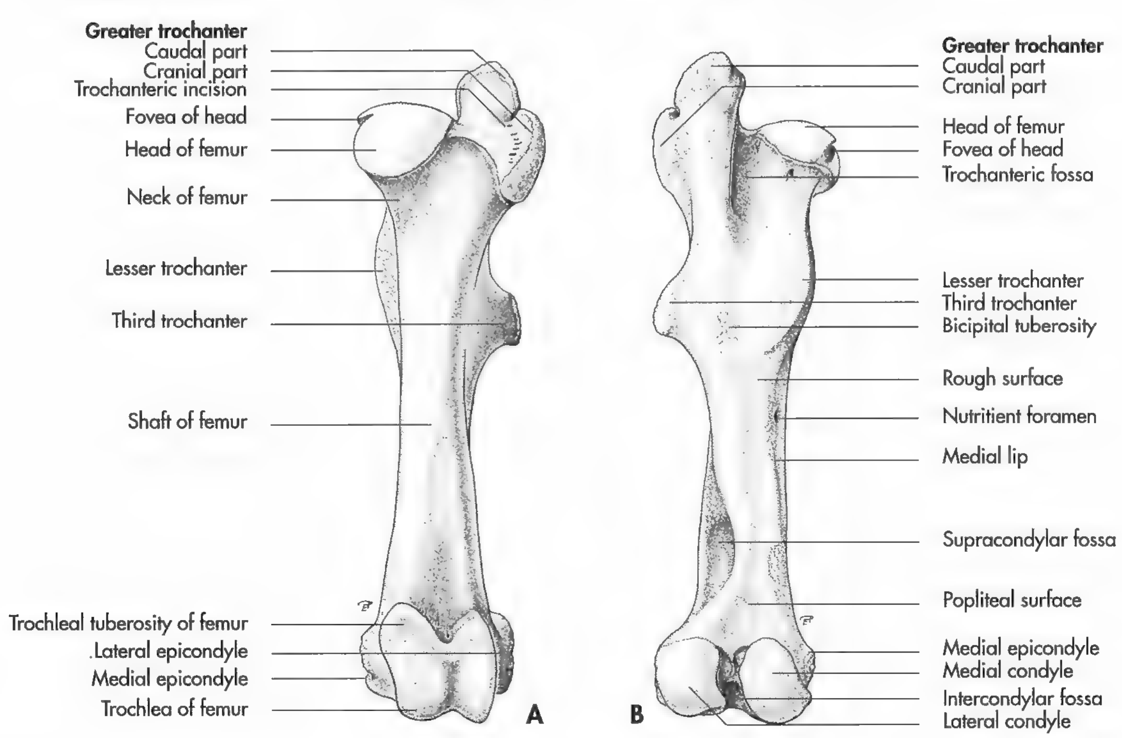

Fig. 4-22. Left femur of the horse (schematic, cranial (A) and caudal (B) aspect).

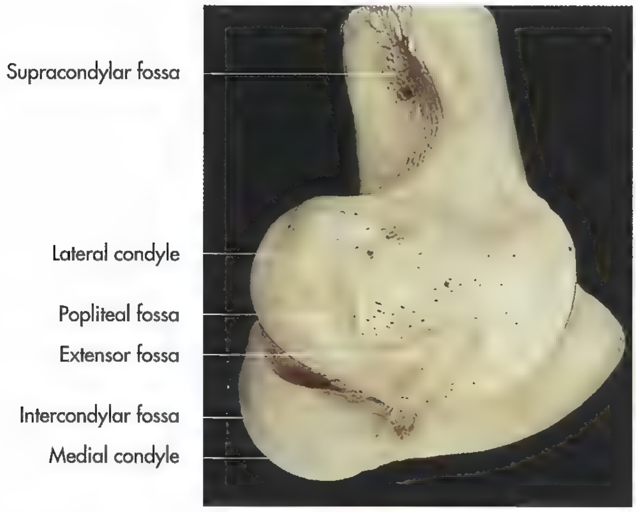

Fig. 4-23. Distal extremity of the right femur of a horse (distolateral aspect).

surface (facies poplitea) by the horizontal **intercondylar line** (linea intercondylaris). The abaxial surfaces of both condyles are roughened for the attachment of the collateral ligaments of the stifle joint (epicondylus lateralis et medialis). The lateral condyle exhibits two depressions, the cranial pit is the **extensor fossa** (fossa extensoria) from which the long digital extensor muscle and the third peroneal muscle arise, the caudal pit (fossa musculi poplitei) gives origin to the popliteal muscle. On the caudal surface of each condyle are small facets for the articulation with the **fabellae** (ossa sesamoidea musculi gastrocnemii), the two sesamoid bones embedded in the tendons of origin of the gastrocnemius muscle (Fig. 4-25). The **femoral trochlea** (trochlea ossis femoris) consists of two ridges, separated by a groove, which articulate with the patella to form the **femoropatellar joint** (articulatio femoropatellaris). These ridges are markedly asymmetrical in large animals, with the medial trochlear ridge being the larger. In the horse the medial ridge carries a protuberance (tuberculum trochleae ossis femoris), that projects proximally. Table 4-2 shows the times of appearance and fusion of the separate ossification centres.

Kneecap (patella)

The patella is a large **sesamoid bone** located in the tendon of insertion of the quadriceps muscle of the thigh. Its **articular surface** (facies articularis) faces caudally towards the femur, the free surface faces cranially (facies cranialis) and is palpable under the skin. The base of the patellar is directed proximally and is roughened for muscular attachment, the apex faces distally. In the horse and the ox the patella is extended medially by the fibrocartilage of the patella (fibrocartilago parapatellaris medialis) (Fig. 4-50, 54 and 57).

Skeleton of the leg (skeleton cruris)

The skeleton of the distal part (zeugopodium) of the free appendage of the hindlimb consists of two bones, the **tibia** and **fibula** (Fig. 4-1 to 4, 30 to 34 and 43). These bones are very dissimilar in strength, like their analogous elements to the forelimb, with the medial bone, the tibia, being by far the stronger of the two. The fibula runs along the lateral border of the tibia and does not articulate with the femur proximally. Thus, only the tibia supports the weight of the animal, which is reflected in an increase in stoutness of this bone. The reduction of the fibula is further progressed than the reduction of the ulna in the forelimb: In cattle the fibula is almost completely reduced, in the horse the proximal part is still a separate bone, whereas the distal part is incorporated in the tibia. In carnivores the fibula is reduced in diameter but not in length.

Tab. 4-2. Times of appearance and fusion of the separate ossification centres of the femur (Ghetie, 1971).

Species	Appearance of the diaphysis nucleus	Appearance in the epiphysis				Fusion in the epiphysis	
		proximal			distal	proximal	distal
		Head of femur	Greater trochanter	Lesser trochanter			
Horse	2nd month of pregnancy	7th month of pregnancy	9th month of pregnancy	12 months after birth	6th month of pregnancy	3 years	3½ years
Ox	2nd month of pregnancy	7th month of pregnancy	11th–12th month of pregnancy	6th month of pregnancy	3 years	3½ years	
Pig	6th week of pregnancy	10th week pregnancy	shortly before birth	shortly before birth	shortly before birth	3 years	3½ years
Carnivores	4th week of pregnancy	3–4 weeks after birth	5 weeks after birth	5 weeks after birth	3 weeks after birth	1–1½ years	1–1½ years

Fig. 4-24. Skeleton of the right stifle joint of a dog (cranial aspect).

Fig. 4-25. Skeleton of the right stifle joint of a dog (caudolateral aspect).

Tibia

The tibia contributes a major part to the formation of the stifle joint (Fig. 4-24, 26 and 34), which is reflected in the expanded proximal extremity of this bone. The proximal extremity of the tibia presents articular surfaces for the corresponding femoral condyles and the menisci and various roughenings for ligamentous attachment. The tibia can be divided into three segments:

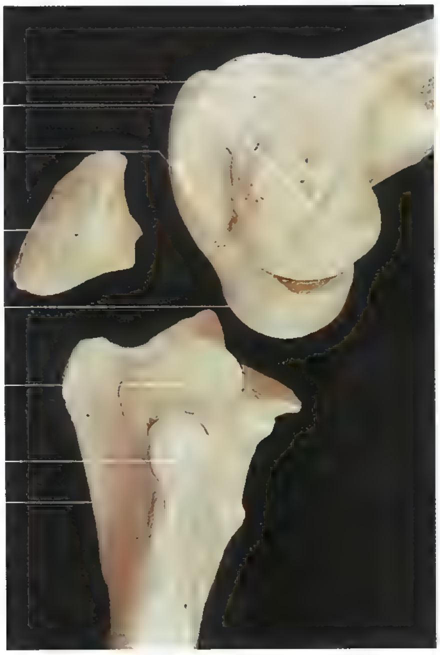

Fig. 4-26. Distal extremity of the left femur, patella and proximal extremity of the tibia of a horse (lateral aspect).

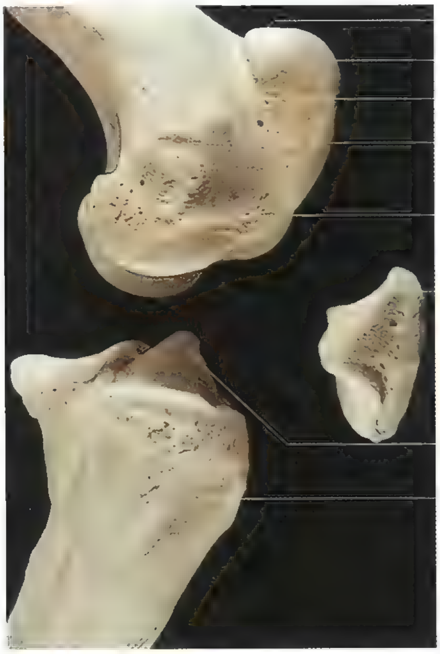

Fig. 4-27. Distal extremity of the left femur, patella and proximal extremity of the tibia of a horse (medial aspect).

Fig. 4-28. Radiograph of the right stifle joint of a dog (craniocaudal projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Fig. 4-29. Radiograph of the right stifle joint of a juvenile dog (mediolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

- Proximal extremity presenting the articular surface (facies articularis) for the formation of the femorotibial joint,
- Tibial shaft (corpus tibiae) and
- Distal extremity bearing the cochlea (cochlea tibiae) for the articulation with the talus.

The **proximal extremity** (extremitas proximalis) is three-sided and carries two condyles (condylus lateralis et medialis), which are separated caudally by the **popliteal notch** (incisura poplitea), where the like-named muscle is found. Each condyle presents an articular surface for the articulation with the corresponding femoral condyle or the distal fibrocartilagenous surface of the meniscus (Fig. 4-34 and 4-35). Between the articular surfaces of the condyles projects the **intercondylar eminence** (eminentia intercondylaris), which is subdivided in a **higher medial part** (tuberculum intercondylare mediale) and a **lower lateral part** (tuberculum intercondylare laterale) by the **central intercondylar area** (area intercondylaris centralis). Cranial and caudal to the intercondylar eminence are depressions for ligamentous attachment (areae intercondylares craniales et caudales). The lateral aspect of the condyle exhibits an articular facet (facies articularis fibularis) for the articulation with the proximal end of the fibula. In ruminants the remnants of the fibula are fused to this articular surface. A deep notch on the craniolateral aspect, the **extensor groove** (sulcus extensorius) gives passage to the long digital extensor muscle.

The **shaft of the tibia** is craniocaudally compressed and carries two prominent osseous structures. The **tibial tuberosity** (tuberositas tibiae) is a large process projecting from the cranial aspect of the proximal part of the tibial shaft and represents an important landmark. Extending distally from the tibial tuberosity is the **cranial border of the tibia** (margo cranialis). It is palpable in the live animal and divides the surface of the shaft into a lateral part, which is covered by muscles and a medial part, which is subcutaneous. In the horse the caudal surface of the shaft is marked by several grooves for the attachments of the popliteal muscle (lineae musculi poplitei) and the flexor muscles of the digit (lineae musculares).

The distal extremity (extremitas distalis) carries the **cochlea,** which consists of an intermediate ridge and two flanking grooves. The central ridge is orientated in a sagittal direction in most domestic species, but in the horse in which it is orientated craniolaterally. The cochlea receives the trochlear ridges of the talus for articulation (Fig. 4-32 and 4-34). The medial side of the cochlea is enlarged by a bony protuberance, the **medial malleolus** (malleolus medialis). The lateral aspect of the cochlea shows species specific variations. In carnivores and the pig the cochlea is notched laterally (incisura fibularis) for the articulation with the distal end of the fibula. In cattle the lateral aspect of the cochlea bears an articular facet for the articulation with the remnant of the distal fibula, the isolated **malleolar bone** (os malleolare). In the horse the lateral malleolus is formed by the fusion of the distal end of the fibula to the tibia.

Fibula

The fibula can be divided into a **proximal head** (caput fibulae), a **neck** (collum fibulae), a **shaft** (corpus fibulae) and a distal extremity or **lateral malleolus** (malleolus lateralis) (Fig. 4-30 and 34). The fibula has undergone remarked reduction during evolution, the degree of which varies among the species. The fibula of the pig and the carnivores has retained its whole length, but is reduced in strength and function. The fibula is separated from the tibia by a long **interosseous space** (spatium

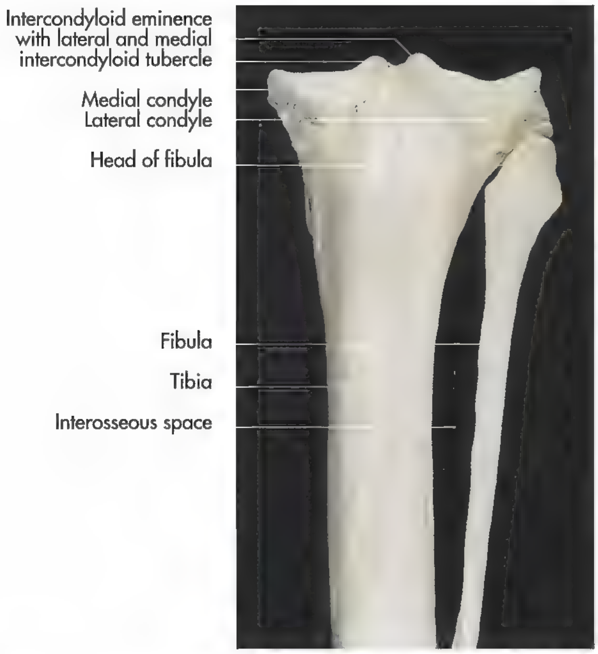

Fig. 4-30. Proximal extremity of the right tibia and fibula of a dog (caudal aspect).

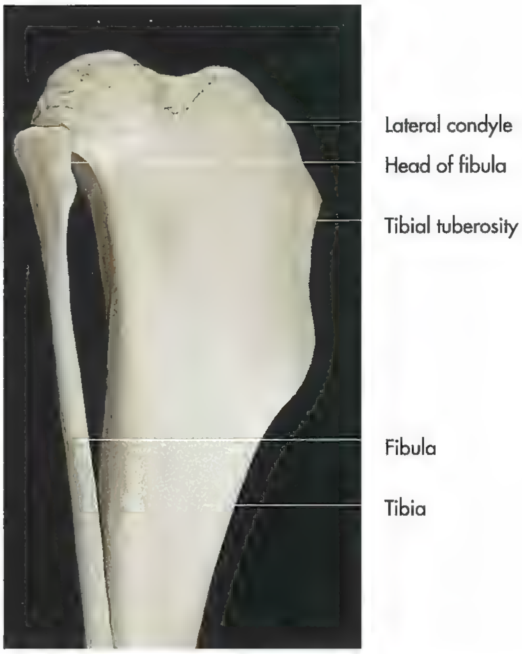

Fig. 4-31. Proximal extremity of the right tibia and fibula of a dog (craniolateral aspect).

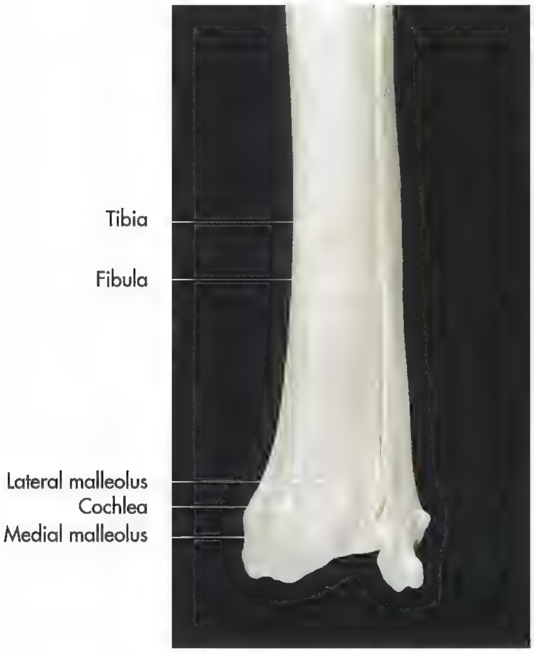

Fig. 4-32. Distal extremity of the right tibia and fibula of a dog (caudal aspect).

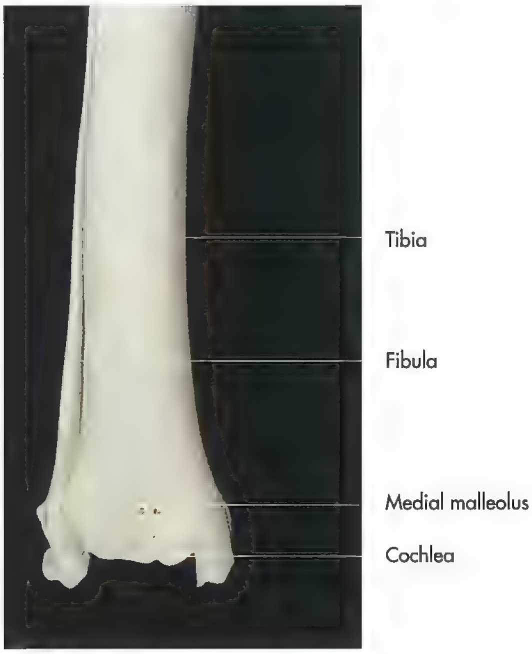

Fig. 4-33. Distal extremity of the right tibia and fibula of a dog (cranial aspect).

interosseum cruris), which is bridged by soft tissue. While the interosseous space extends the whole length of the leg in the pig, it is limited to the proximal part in carnivores. The fibula runs lateral to the tibia and divides the muscles of the leg into a cranial and a caudal group. It can be palpated over its whole length in thin dogs, whereas in heavily muscled dogs only the proximal extremity is palpable. The head of the fibula articulates with the lateral condyle of the tibia.

In ruminants the shaft of the fibula is completely reduced. The proximal extremity is fused to the tibia and the distal part persists as an isolated bone (os malleolare), which articulates with the distal extremity of the tibia. In the horse only the proximal part of the fibula remains isolated. The head articulates with the tibia and the shaft fades towards the middle of the leg. The distal extremity is completely incorporated into the tibia and forms the lateral malleolus, which has a separate

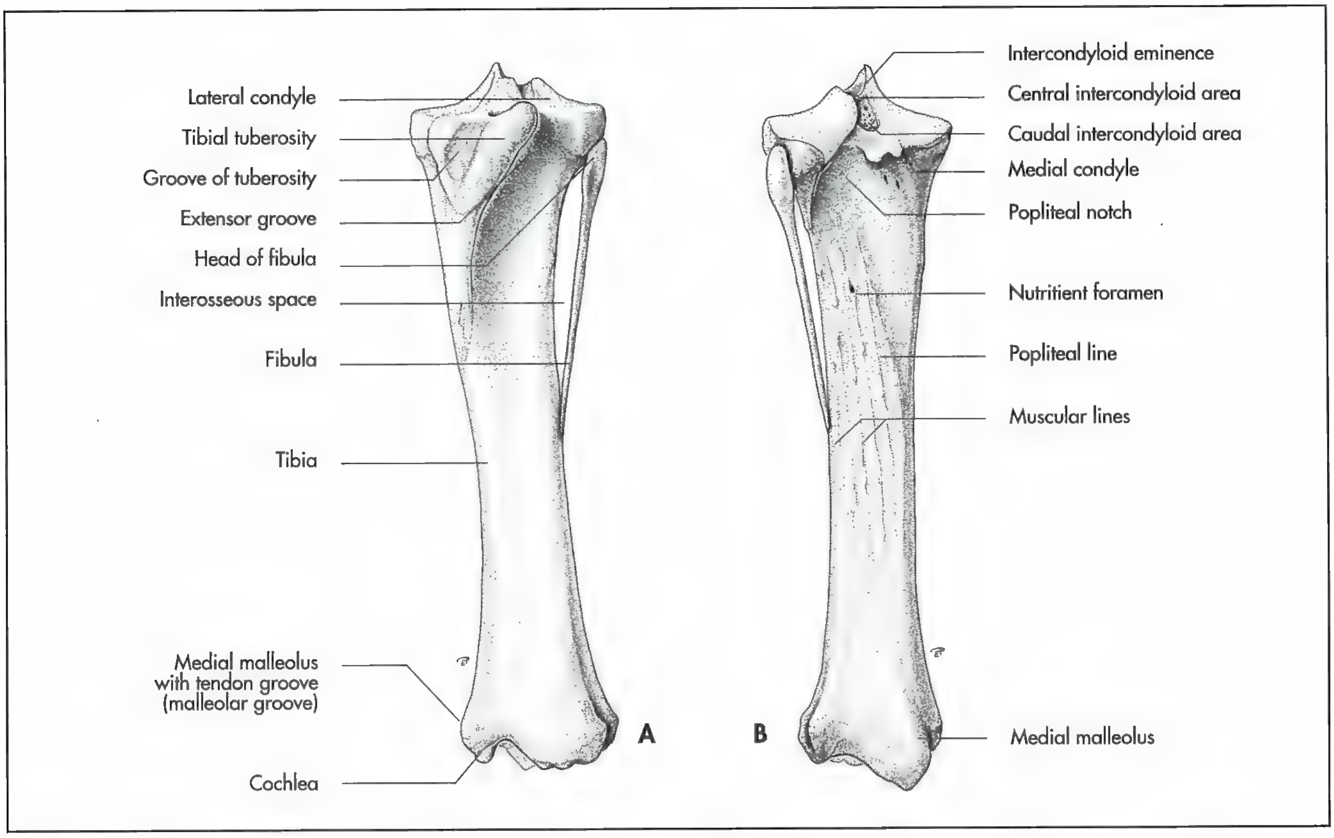

Fig. 4-34. Left tibia and fibula of the horse (schematic, cranial **(A)** and caudal **(B)** aspect).

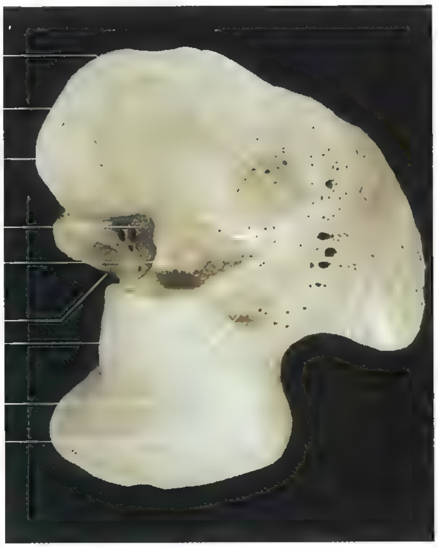

Fig. 4-35. Proximal extremity of the right tibia of a horse (end view).

Fig. 4-36. Proximal extremity of the left tibia of a horse (caudal aspect).

ossification centre, visible radiographically in the juvenile horse.

Skeleton of the pes (skeleton pedis)

The skeleton of the pes forms the osseous part of the autopodium and consists from proximal to distal of three segments:

Tab. 4-3. Times of appearance and fusion of the separate ossification centres of the tibia (Ghetie, 1971).

Species	Appearance of the diaphysis nucleus	Appearance in the epiphysis			Fusion in the epiphysis	
Tibia		proximal		distal	proximal	distal
		Condyle	Tuberosity			
Horse	2nd month of pregnancy	7th month of pregnancy	9th month of pregnancy	9th month of pregnancy	3½ years	2 years
Ox	2nd month of pregnancy	middle of 6th –7th month of pregnancy	9th month of pregnancy	middle of 7th –8th month of pregnancy	3½–4 years	2–2½ years
Sheep	6th –8th week of pregnancy	4th month of pregnancy	around birth	3rd month of pregnancy	3½ years	15–20 months
Pig	2nd month of pregnancy	shortly before birth	a few weeks after birth	shortly before birth	3½ years	2 years
Carnivores	4th week of pregnancy	end of 1st month after birth	a few weeks after birth	end of 1st month after birth	12 months	12 –13 months

- Basipodium: tarsal bones (ossa tarsi),
- Metapodium: metatarsal bones (ossa metatarsalia) and
- Acropodium: phalanges (ossa digitorum pedis).

Tarsal bones (ossa tarsi)

In the domestic mammals the tarsal bones are arranged in three rows, the **proximal or crural row,** the **middle or intertarsal row** and the **distal or metatarsal row** (Fig. 4-37 to 43). The proximal row articulates with the tibia, forming the **tarsocrural joint** (articulatio tarsocruralis), the distal row articulates with the metatarsal bones to form the **tarsometatarsal joint** (articulatio tarsometatarseae). Neighbouring tarsal bones articulate with each other in a complex fashion, which is described in detail later in this chapter (Fig. 4-37 and 39). The tarsus contains the following bones:

Proximal or crural row (in mediolateral sequence)
- Tibial tarsal bone or talus (os tarsi tibiale),
- Fibular tarsal bone or calcaneus (os tarsi fibulare),
- Middle or intertarsal row and
- Central tarsal bone (os tarsi centrale).

Distal or metatarsal row (in mediolateral sequence)
- First tarsal bone (os tarsale primum),
- Second tarsal bone (os tarsale secundum),
- Third tarsal bone (os tarsale tertium) and
- Fourth tarsal bone (os tarsale quartum).

The pattern of the tarsal bones varies in the different species and is illustrated in Fig 4-41.

In carnivores and pigs the original number of **seven tarsal bones** is maintained. The tarsus of the ruminants consists of **five tarsal bones,** the central and fourth and the second and third tarsal bones are fused. In the horse the first and second tarsal bones are fused, so that the total numbers of **tarsal bones** is reduced to **six.**

Talus (os tarsi tibiale)

The talus is the medial bone of the proximal row of the tarsus. It is divisible into a compact **body** (corpus tali), a **trochlea** (trochlea tali) with prominent sagittal ridges dorsoproximally and a cylindrical **head** (caput tali) as the base of the bone (Fig. 4-37 to 43). The **trochlea of the talus** articulates with the sagittal grooves and the intermediate ridge of the distal end of the tibia. The sagittal ridges of the trochlea are less prominent and extend further distal in the carnivores than in other domestic animals and account for the increased mobility in the tarsus compared to other species. The sides of the trochlea articulate with the distal end of the fibula and the medial malleolus (Fig. 4-42 and 43). In the horse the trochlear ridges are orientated obliquely in a mediolateral direction thus causing a forward and outward movement of the digit during flexion of the tarsus (Fig. 4-37). The trochlear ridges of the ruminants are directed sagittally. The trochlea of the talus articulates with the malleolar bone laterally and with the medial malleolus of the tibia medially.

The head of the talus forms a smaller distal trochlea for the articulation with the central tarsal bone in all domestic species, but the horse, which exhibits a more or less flat articular surface towards the central tarsal bone. In carnivores the head of the talus is separated from the body by a distinct **neck** (collum tali). The distal trochlea is well defined in ruminants and articulates with the combined central and fourth tarsal bones (os centroquartale). The distal trochlea is less distinct than in ruminants and results in a decreased range of movement in

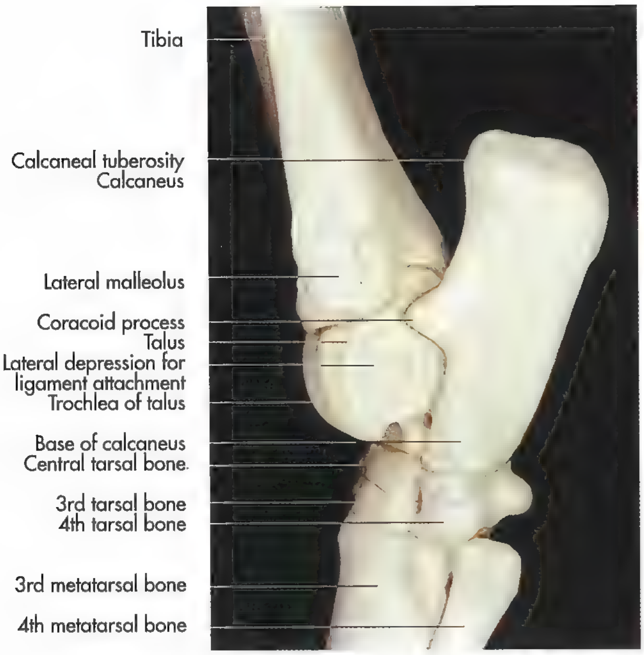

Fig. 4-37. Skeleton of the left tarsus of a horse (lateral aspect).

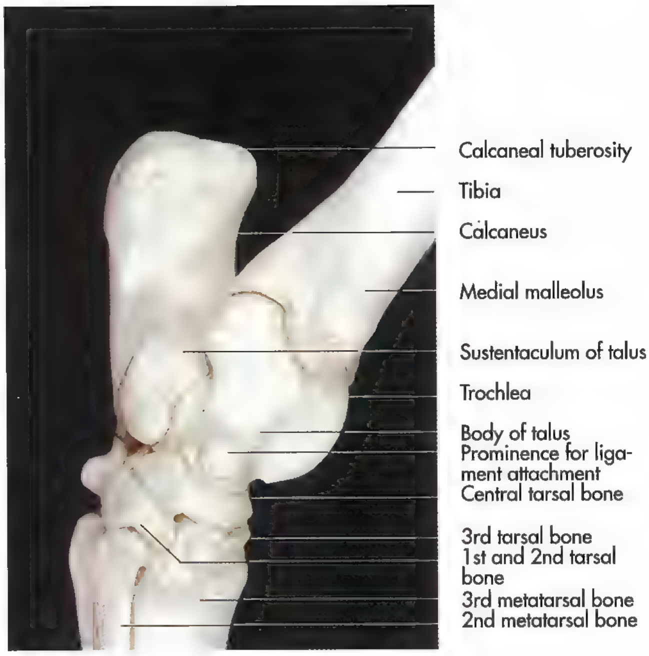

Fig. 4-38. Skeleton of the left tarsus of a horse (medial aspect).

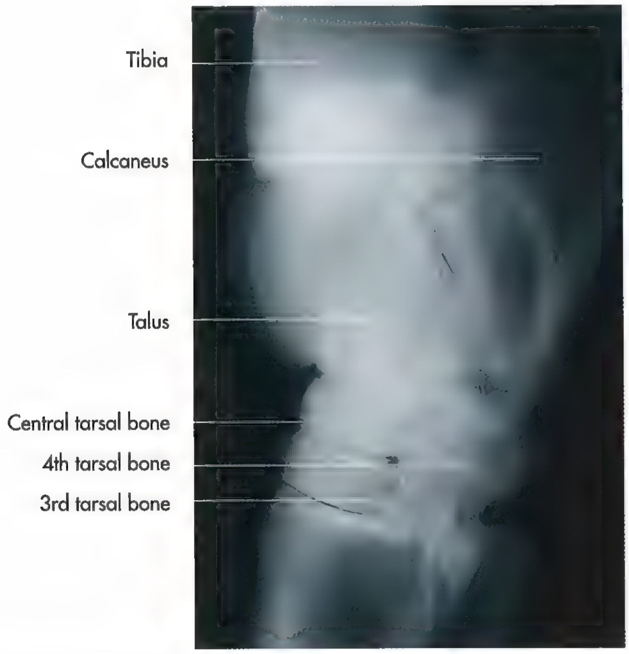

Fig. 4-39. Radiograph of the left tarsus of a horse (lateromedial projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

Fig. 4-40. Radiograph of the right tarsus of a dog (mediolateral projection) (courtesy of Prof. Dr. Sabine Breit, Vienna).

this joint. The plantar and lateral aspects of the talus articulate with the calcaneus.

Calcaneus (os calcis, os tarsi fibulare)

The calcaneus lies lateral and plantar to the talus and provides the osseous base of the **point of the hock** (calx) (Fig. 4-37 and 39). It presents articulating surfaces towards the talus medially and dorsally and towards the fourth tarsal bone distally. The **calcaneal tuberosity** (tuber calcanei) extends the calcaneus proximally beyond the talus to form the prominent point of the hock, which is an important landmark in live animals. It serves as a lever for the muscles which extend the **hock** (tarsus). A shelf-like process, the **sustentaculum of talus** (sustentacu-

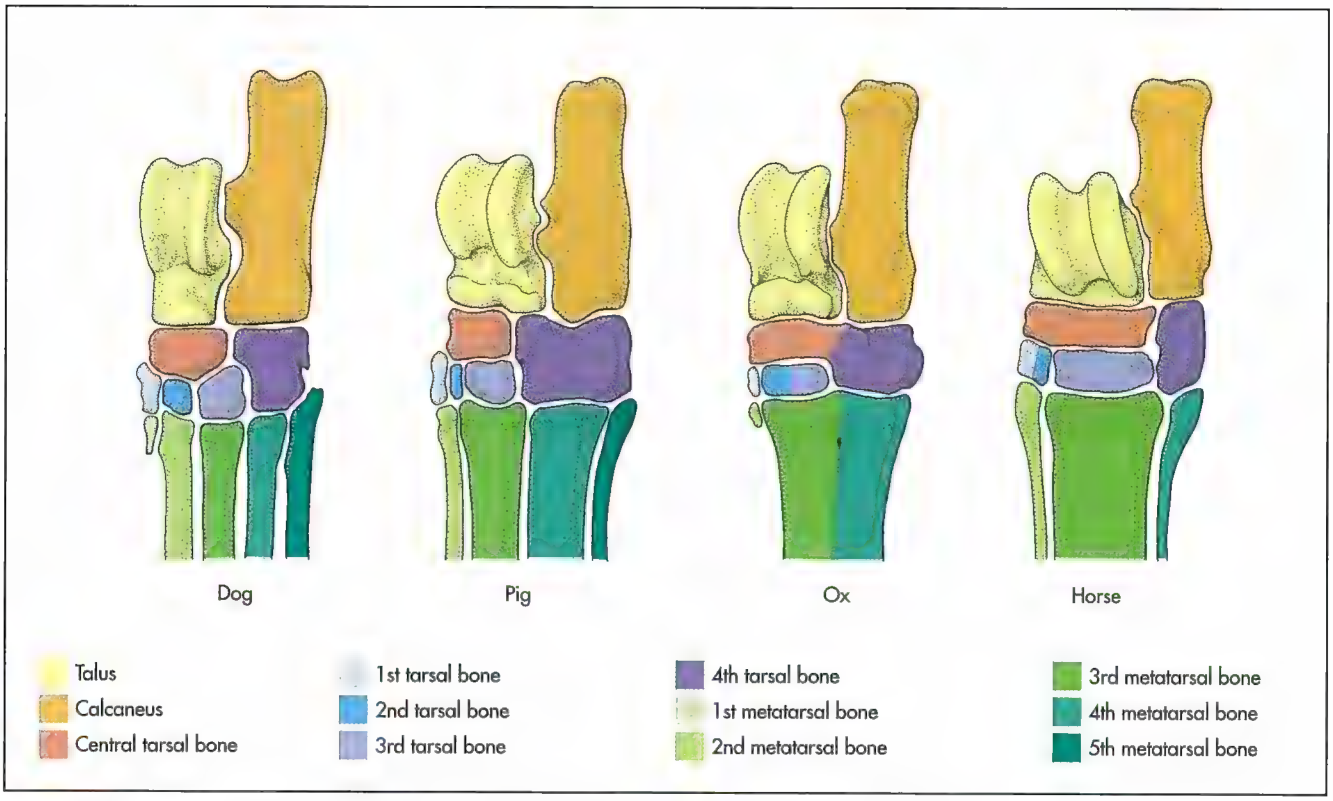

Fig. 4-41. Skeleton of the tarsus in the domestic mammals (schematic) (Ellenberger and Baum, 1943).

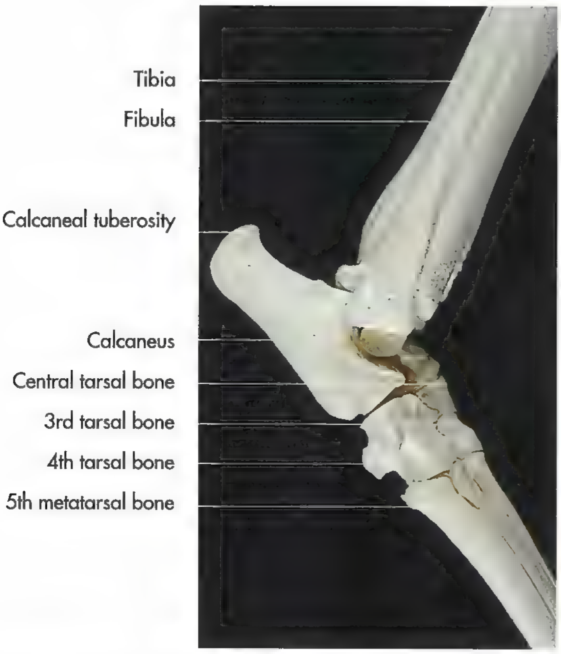

Fig. 4-42. Skeleton of the right tarsus of a dog (lateral aspect).

Fig. 4-43. Skeleton of the right tarsus of a dog (plantar aspect).

Tab. 4-4. Times of appearance and fusion of the separate ossification centres of the tarsal bones.

Species	Appearance of the ossification centres						
	proximal row		Central tarsal bone	distal row			
	Calcaneus	Talus		4th tarsal bone	3rd	2nd	1st
Horse	4th month of pregnancy	4th month of pregnancy	6th month of pregnancy	end of 5th month of pregnancy	7th month of pregnancy	10th month of pregnancy fusion of 1st and 2nd tarsal bones	
Ox	4th month of pregnancy	4th month of pregnancy	6th month of pregnancy shortly after birth fusion of central tarsal bone and 4th tarsal bone	end of 5th month of pregnancy	7th month of pregnancy fusion of 2nd and 3rd tarsal bones		8th month of pregnancy
Pig		shortly before birth		around the time of birth	shortly after birth		
Carnivores	around the time of birth		at the end of the first month after birth				

lum tali), is present on the medial side of the distal part of the calcaneus (Fig. 38, 40 and 43). It overlaps the talus on its plantar aspect and supports the deep digital flexor tendon. In ruminants the calcaneal tuberosity is expanded and the proximal aspect is roughend and hollowed by a shallow groove. In the horse, the calcaneal tuberosity is very pronounced and its proximal surface is marked by a groove. A pointed **process** (processus coracoideus) is situated at the base of the calcaneus for articulation with the fourth tarsal bone.

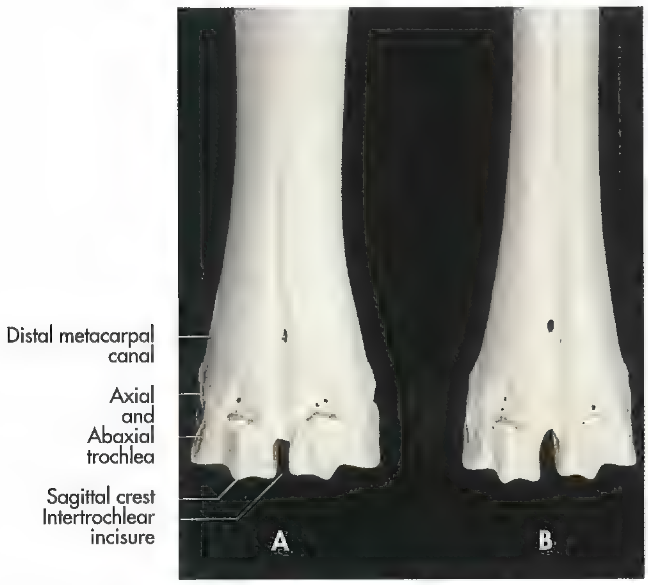

Fig. 4-44. Distal part of the right metacarpal **(A)** and metatarsal **(B)** bone of an ox (dorsal aspect).

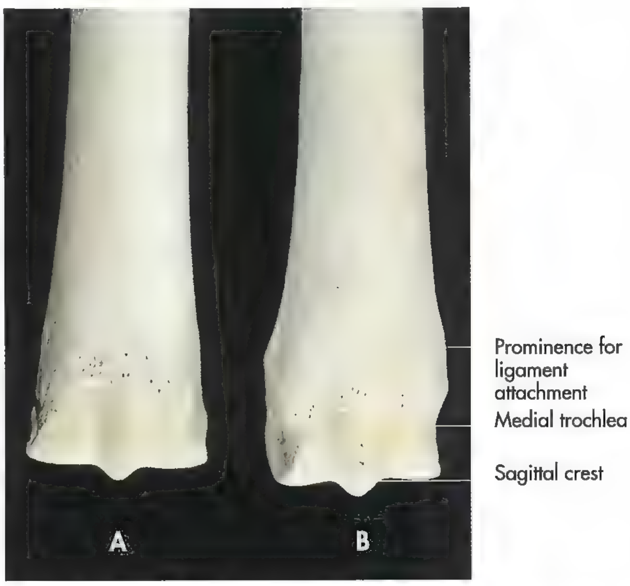

Fig. 4-45. Distal part of the metacarpal **(A)** and metatarsal **(B)** bone of a horse (dorsal aspect).

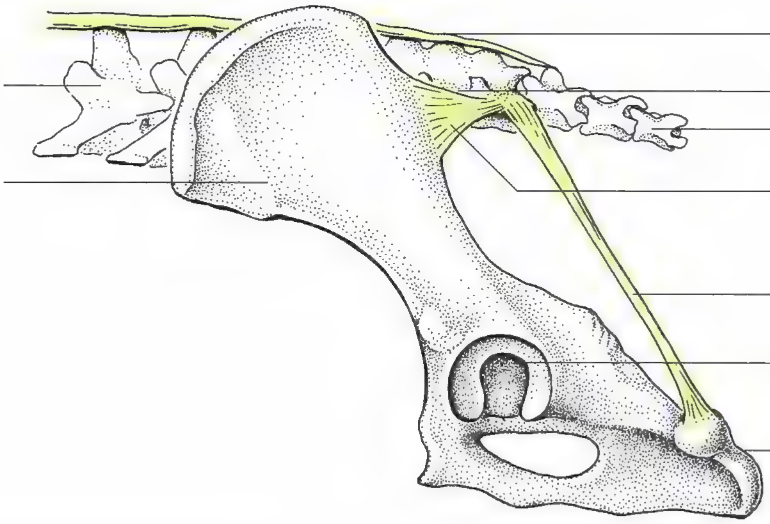

Fig. 4-46. Sacrotuberous ligament of the dog (schematic).

Metatarsal and digital skeleton (ossa metatarsalia et ossa digiti pedis)

The skeleton of the metatarsus and phalanges closely resemble those of the forelimb. The metatarsal bones tend to be longer and more slender with a stronger cortex than the corrsponding metacarpal bones. The **cannon bone** (third metatarsal bone) of the equine hindlimb is circular in crossection, whereas the **cannon bone** (third metacarpal bone) of the forelimb is oval (Fig. 4-44 and 45). In cattle an additional sesamoid bone can be present just proximal to the third metatarsal bone. The phalangeal and sesamoid bones of the hindlimb are almost identical to the forelimb. The hoof of the hindfoot is narrower than that of the front foot, the toe longer and the angle of the hoofwall steeper.

Joints of the pelvic limb (articulationes membri pelvini)

The pelvic limb is joined to the trunk by the **pelvic girdle** (cingulum membri pelvini), which is formed from the combined ilium, ischium and pubis. The **hip bones** (ossa coxae) are united midventrally by fibrous cartilage to form the **pelvic symphysis** (symphysis pelvina). The cranial pubic symphysis ossifies with advancing age, whereas the caudal ischial symphysis remains unossified in most species. The ilium articulates dorsally with the sacrum forming the sacroiliac joint. The two hip bones, the sacrum and the first caudal vertebra constitute the bony pelvis. The cranial pubic ligament (ligamentum pubicum craniale) connnects the free borders of the pubic bones. The **obturator membrane** (membrana obturatoria) is a thin layer of fibrous tissue, which covers the obturator foramen.

Sacroiliac joint (articulatio sacroiliaca)

The sacroiliac joint is a tightly apposed **synovial joint** formed by the auricular surfaces (facies auriculares) of the wing of the ilium and the wing of the sacrum. The articular surfaces are covered by cartilage. The joint capsule fits closely to the joint and is enforced by the **ventral sacroiliac ligaments** (ligamenta sacroiliaca ventralia). The **sacroiliac ligaments** (ligamenta sacroiliaca) are the:

- **Interosseous sacroiliac ligaments** (ligamenta sacroiliaca interossea) extending between the iliac tuberosity of the wing of the ilium and the dorsal surface of the wing of the sacrum.
- **Dorsal sacroiliac ligaments** (ligamenta sacroiliaca dorsalia), which are divided into two branches. The short branch (pars breve) extends between the sacral tuber and the mammilary processes (carnivores and pig) or the spinous processes (ruminants and horse) of the sacrum. The long branch (pars longa) extends between the sacral tuber and the lateral part of the sacrum (Fig. 4-47 and 48).

The **sacrotuberous ligament** (ligamentum sacrotuberale) is a fibrous cord in the dog extending between the transverse process of the last sacral vertebrae and the ischial tuberosity (Fig. 4-46). It is absent in the cat. In ungulates it is expanded to a broad sheet extending between the lateral part of the sacrum in the ox or the transverse processes of the first caudal vertebrae in the horse and pig, and the dorsal border of the ilium and ischium (Fig. 4-47 and 48). It is therefore named the **broad sacrotuberous ligament** (ligamentum sacrotuberale latum). The lesser and the greater ischiatic foramen (foramen ischiadicus majus and minus) remain uncovered to allow the passage of vessels, nerves and tendons. The caudal border of this ligament is visible under the skin in the ox, but covered by muscles in the horse and pig.

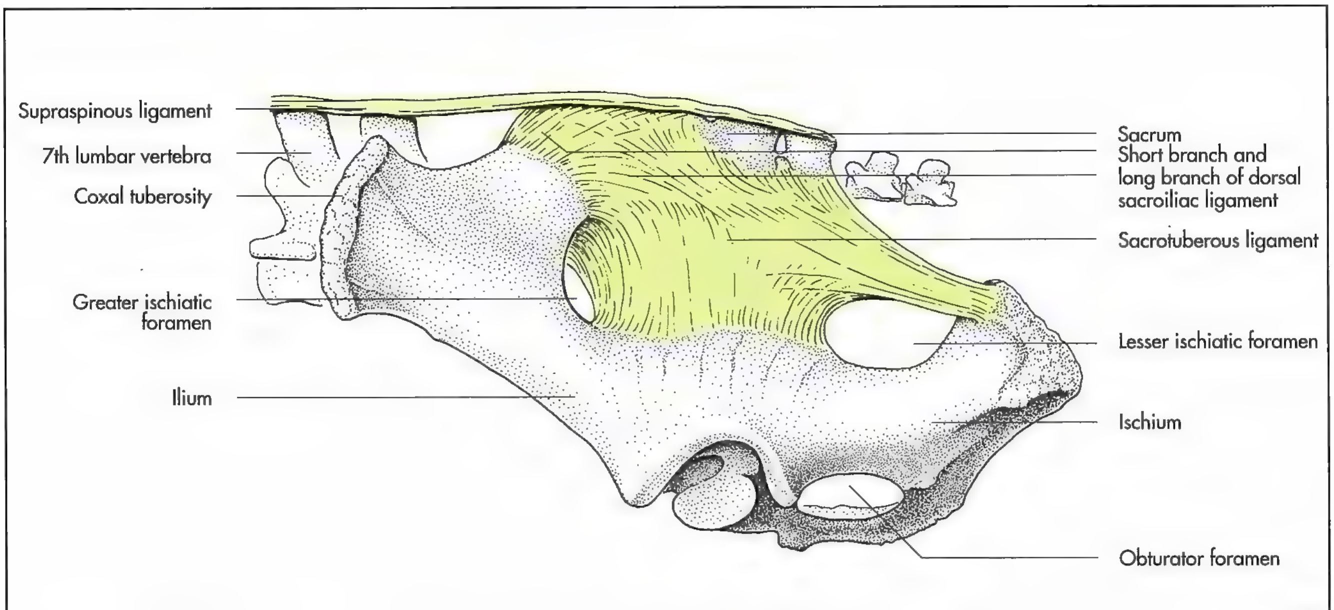

Fig. 4-47. Ligaments of the pelvis of the ox (schematic) (Červeny, 1980).

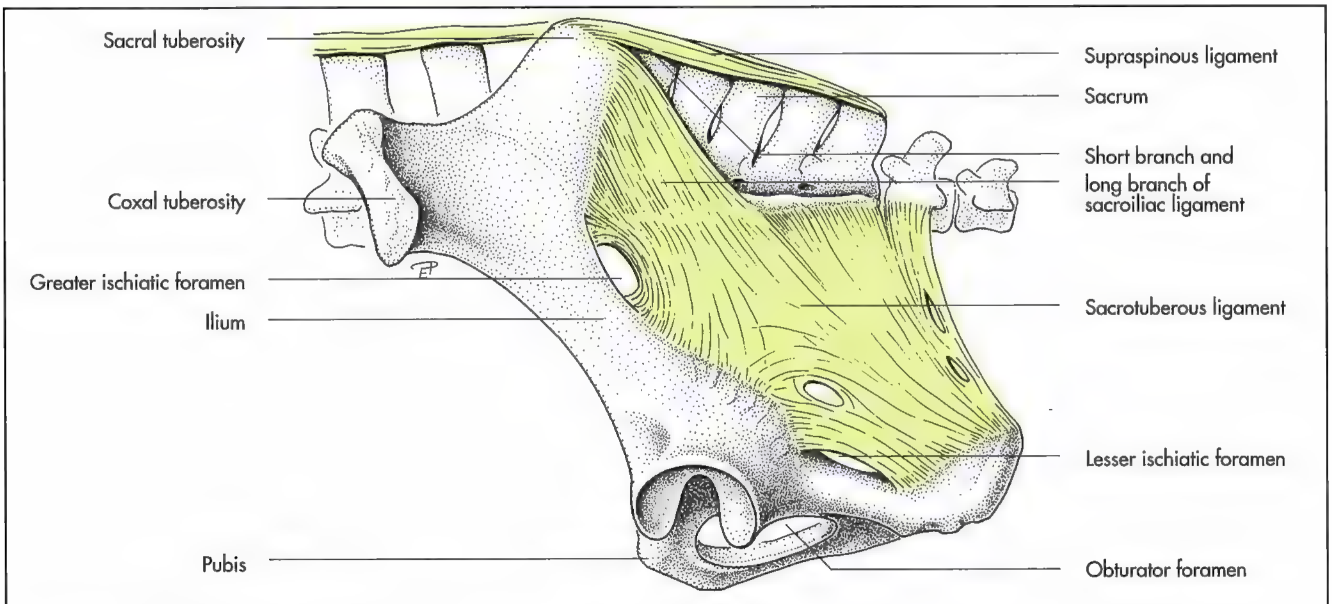

Fig. 4-48. Ligaments of the pelvis of the horse (schematic) (Ghetie, Pastea and Riga, 1955).

Coxofemoral or hip joint (articulatio coxae)

The hip joint is a **spheroidal joint** formed by the head of the femur articulating with the acetabulum. The acetabulum is deepened by a band of fibrocartilage, the **acetabular lip** (labrum acetabulare), which is applied to the acetabular rim.

The joint capsule is spacious and attaches to the acetabular lip. It is indented by the ligament of the **head of the femur** (ligamentum capitis ossis femoris). In ungulates the range of movement is largely restricted to flexion and extension with a limited capacity of rotation, adduction and abduction. This restriction of movement in the spheroidal hip joint is due to the shape of the femoral head (Fig. 4-49), the intraarticular ligaments and the massive muscles of the thigh. These structures allow a greater range of movement in the dog and the cat, compared to the other domestic species.

Ligaments of the hip joint (Fig. 4-49):

- **Ligament of the head of the femur,** which extends from the fovea in the head of the femur to the acetabular fossa. It is largely intracapsular and covered by synovial membrane.

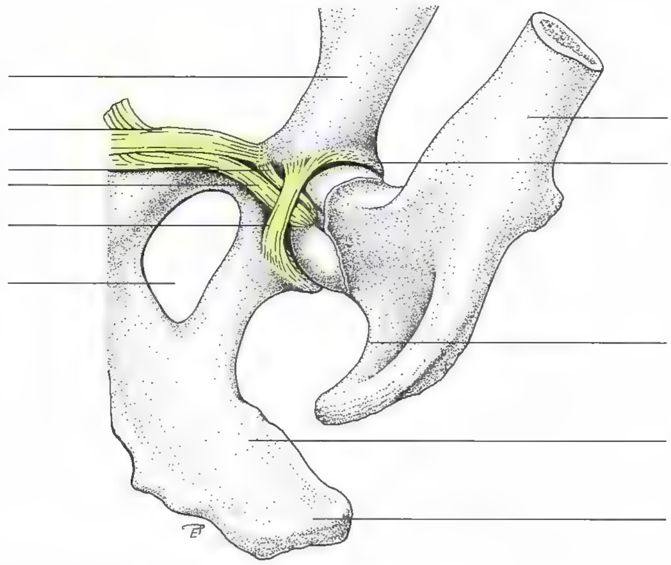

Fig. 4-49. Left hip joint of the horse (schematic) (Ghetie, 1967).

- **Accessory ligament of the femur** (ligamentum accessorium ossis femoris), which is only present in the horse. It is detached from the straight muscule of the abdomen, which has its origin at the cranial pubic ligament. It passes through the acetabular notch and inserts close to the ligament of the head of the femur in the fovea of the head of the femur.
- **Transverse acetabular ligament** (ligamentum transversum acetabuli), which bridges the acetabular notch and keeps the other two ligaments in place.

Injection sites:

- **Dog:** The dog is put in lateral recumbency. The femur should be at a 90° angle to the vertebral column. The needle is inserted at the craniodorsal border of the greater trochanter. The needle is directed caudally and advanced parallel to the neck of the femur.
- **Ox:** The animal should stand squarely. A 20 cm needle is inserted just cranial to the greater trochanter and advanced in a slightly caudoventral direction.
- **Horse:** The horse should stand squarely and restrained within stocks. The greater trochanter should be palpated and a 15 cm needle inserted just caudal to it, into the trochanteric notch. The needle is directed in a horizontal plane craniomedially in a 45° angle to the long axis of the horse.

Stifle joint (articulatio genus)

The stifle joint is a **composite, incongruent hinge joint** (Fig. 4-50 to 61). It comprises:

- **Femorotibial joint** (articulatio femorotibialis) formed by the femur and tibia and
- **Femoropatellar joint** (articulatio femoropatellaris) formed by the femur and patella.

Femorotibial joint (articulatio femorotibialis)

The femorotibial articulation is formed between the condyles of the femur and the proximal end of the tibia.

To compensate for the **incongruency of the articular surfaces**, a **meniscus** (meniscus articularis) is interposed between each femoral condyle and the tibia. The menisci are semilunar fibrocartilages with a thick and convex peripheral border and a central thin and concave border. They have a concave proximal surface facing towards the femoral condyle and a flattened distal surface towards the tibia (Fig. 4-54 and 60).

Although a **condylar joint** with the chief movements being **flexion** and **extension** the mobility of the menisci allows a limited degree of rotational movement to the stifle joint. The spiral configuration of the femoral condyles and the eccentric insertion of the collateral ligaments in relation to the axis of the joint movement tightens the ligaments and slows down the movement when the joint moves toward the extended position.

The joint capsule is spacious and its **fibrous layer** (membrana fibrosa) is attached to the margin of the articular surfaces and the menisci, thus completely enclosing the femoral condyles (Fig. 4-58). The **synovial layer** (membrana synovialis) of the joint capsule covers the cruciate ligaments and forms a partition, complete only in horses, between the medial and lateral femorotibial joint. The two femorotibial joint sacs are further separated by the menisci into two freely communicating compartments, a proximal and distal one.

The lateral femorotibial joint has two pouches. One pouch ensheaths the tendon of the long digital extensor muscle at its origin from the extensor fossa, the other invests the tendon of origin of the popliteal muscle (Fig. 4-58 and 59).

Ligaments of the femorotibial joints can be divided into the:

- Ligaments of the menisci and
- Ligaments of the femorotibial joints.

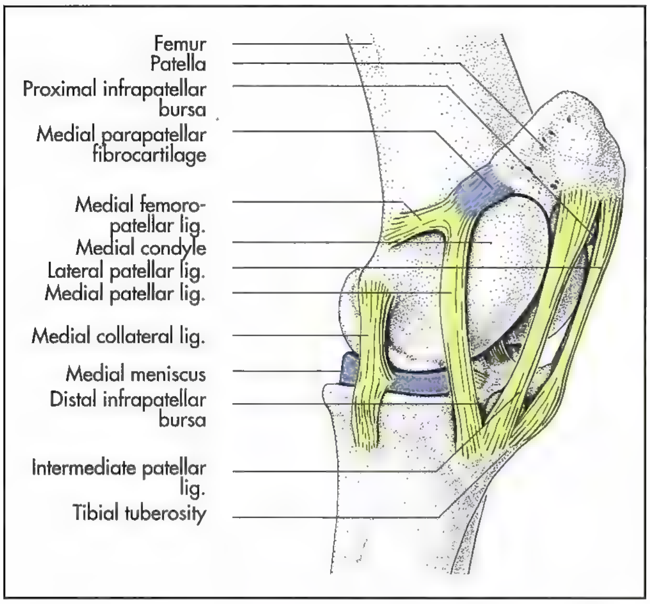

Fig. 4-50. Ligaments of the left stifle joint of the horse (schematic, medial aspect) (Ghetie, Pastea and Riga, 1955).

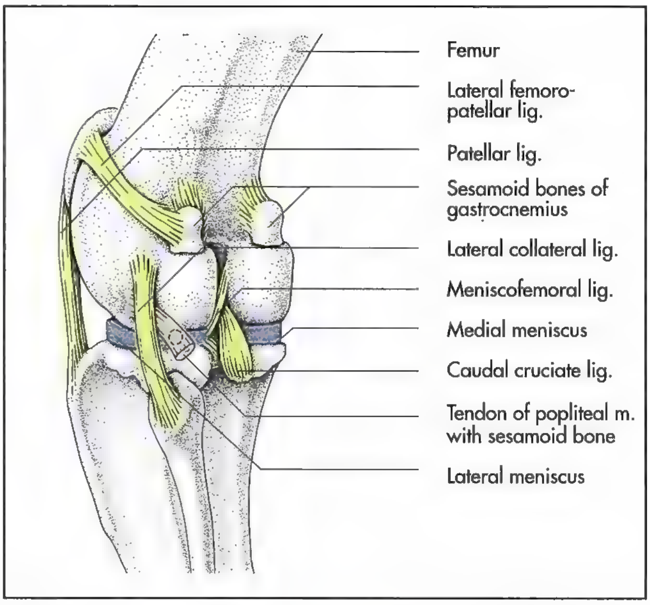

Fig. 4-51. Left stifle joint of the dog (schematic, caudolateral aspect).

Fig. 4-52. Ligaments of the left stifle joint of a dog (dorsal aspect) (courtesy of Dr. R. Macher, Vienna).

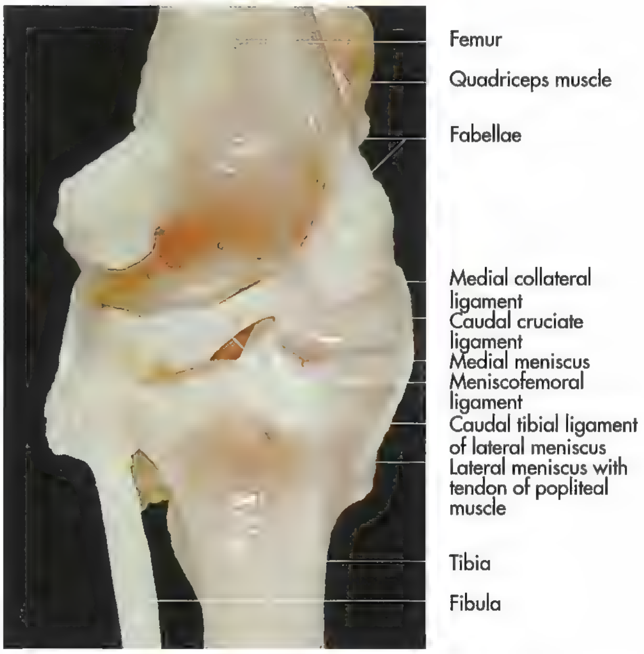

Fig. 4-53. Ligaments of the left stifle joint of a dog (caudal aspect) (courtesy of Dr. R. Macher, Vienna).

Each mensicus is attached to the proximal tibia by cranial and caudal ligaments. The lateral meniscus has an additional ligament to the distal femur.

Meniscal ligaments (Fig. 4-54, 55, 60 and 61):

- **Cranial tibial ligaments of the menisci** (ligamentum tibiale craniale menisci lateralis and medialis): They extend from the cranial part of each meniscus to the lateral and medial cranial intercondyloid area of the tibia.
- **Caudal tibial ligaments of the menisci** (ligamentum tibiale craniale menisci lateralis and medialis): The lateral ligament extends from the caudal angle of the lateral meniscus to the popliteal notch of the tibia. The medial ligament from the caudal angle of the medial meniscus to the caudal intercondyloid area of the tibia.
- **Femoral ligament of the lateral meniscus** (ligamentum meniscofemorale): It passes from the caudal angle of the lateral meniscus to the inside of the medial femoral condyle.
- **Transverse ligament** (ligamentum transversum genus): It connects the cranial angles of the two menisci in carnivores and in some bovine individuals.

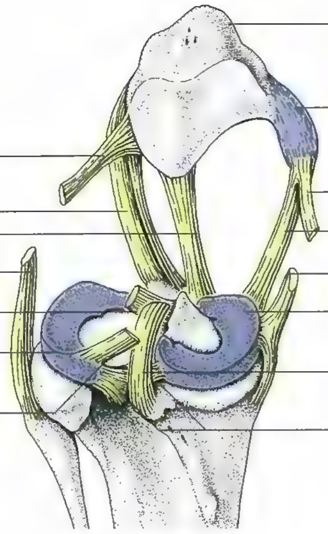

Fig. 4-54. Ligaments of the left stifle joint of the horse after removal of the distal end of the femur (schematic, caudal aspect) (Ghetie, 1967).

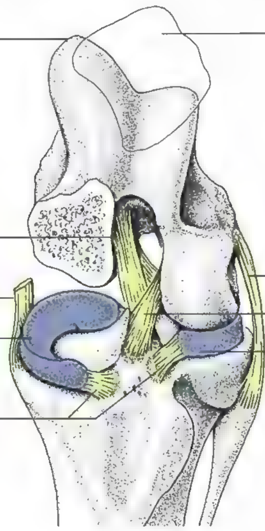

Fig. 4-55. Ligaments of the left stifle joint of the horse after removal of the medial femoral condyle (schematic, dorsal aspect) (Červeny, 1980).

Femorotibial ligaments (Fig. 4-50, 51 and 54):

- **Lateral** and **medial collateral ligaments** (ligamentum collaterale laterale et mediale):
  The lateral or fibular collateral ligament arises from the lateral epicondyle of the femur and ends with one branch on the lateral condyle of the tibia and with a stronger branch on the head of the fibula.
  The medial or tibial collateral ligament extends between the medial epicondyle of the femur and a roughened area distal to the margin of the medial condyle of the tibia. It fuses with the joint capsule and the medial meniscus.
- **Cranial** and **caudal cruciate ligament of the stifle** (ligamenta cruciata genus): The cruciate ligaments are mainly situated in the intercondyloid fossa of the femur between the two synovial sacs of the femorotibial joints. The cranial cruciate ligament arises in the intercondylar area of the lateral femoral condyle, extends craniodistally and inserts on the central intercondylar area of the tibia. The caudal cruciate ligament is attached to the intercondylar area of the medial femoral condyle, is directed caudodistally and ends on the popliteal notch of the tibia.
- **Oblique popliteal ligament** (ligamentum popliteum obliquum) consists of fibrous strands embedded within the joint capsule running in a latero-proximal to mediodistal orientation.

Fig. 4-56. Right stifle joint of a horse (lateral aspect) (courtesy of Dr. Margit Teufel, Vienna).

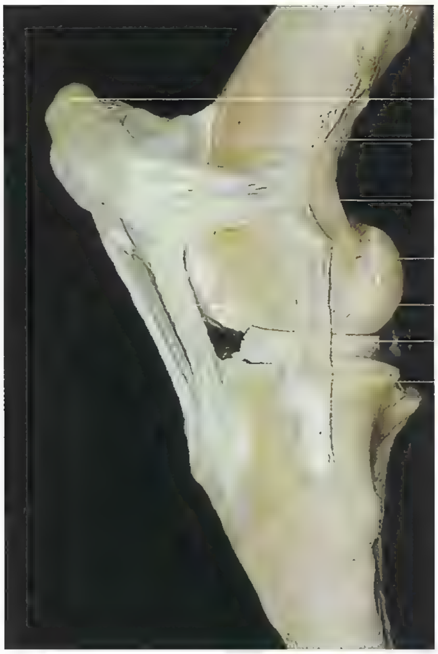

Fig. 4-57 Right stifle joint of a horse (medial aspec) (courtesy of Dr. Margit Teufel, Vienna).

Fig. 4-58. Acrylic cast of the left stifle joint of a horse (medial aspect) (courtesy of Dr. Margit Teufel, Vienna).

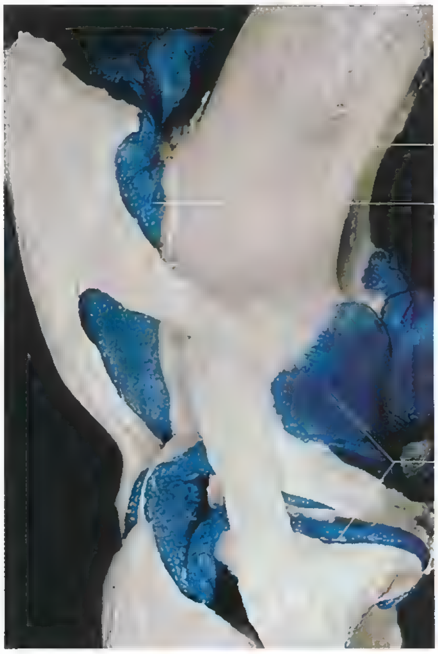

Fig. 4-59. Acrylic cast of the left stifle joint of a horse (lateral aspect) (courtesy of Dr. Margit Teufel, Vienna).

Femoropatellar joint (articulatio femoropatellaris)

The femoropatellar joint is formed by the articular surface of the patella and the femur. Since the patella resembles a sledge sliding on the trochlea of the femur, it is classified as a **sledge joint.** The **ligaments of the femoropatellar joint** (Fig. 4-50, 54 and 56) can be divided into:

- Patellar retinacula (retinacula patellae),
- Femoropatellar ligaments (ligamentum femoropatellare laterale et mediale) and
- Patellar ligament (ligamentum patellae).

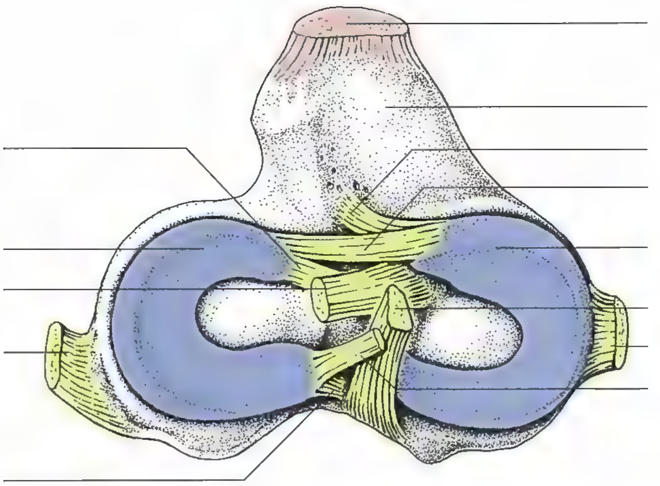

Fig. 4-60. Proximal end of the left tibia with menisci of the dog (schematic) (Červeny, 1980).

The **patellar retinacula** are strands of connective tissue, detached from the regional fascia between the tendon of the quadriceps muscle, the patella, the femoral condyles and the trochlea of the tibia.

The medial and lateral femoropatellar ligaments are bands of loose fibres, partially blended with the overlying retinacula. They extend between the epicondyles of the femur and the same side of the patella.

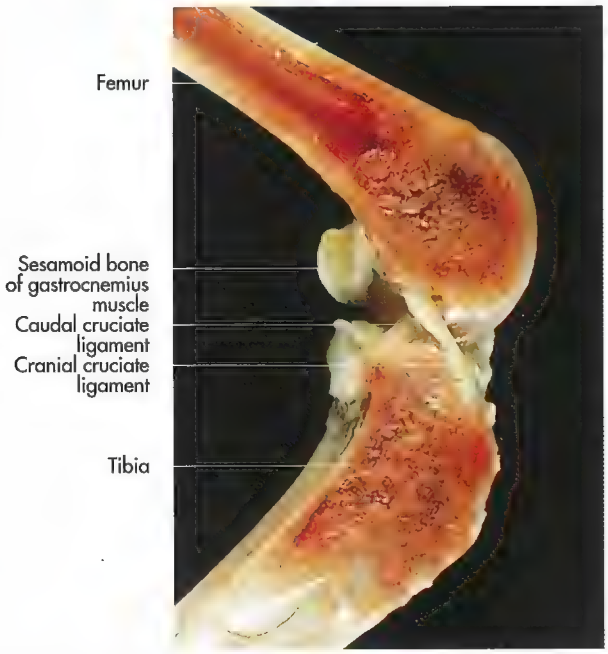

Fig. 4-61. Cruciate ligaments of a cat (paramedian section) (courtesy of Dr. Sabine Langer, Vienna).

The patella is joined to the tibial tuberosity by a single patellar ligament in carnivores, the pig and small ruminants and by three patellar ligaments in cattle and the horse. The **single patellar ligament** of carnivores, the pig and small ruminants is identical to the **middle patellar ligament** (ligamentum patellae intermedium) in the other species and is formed by the distal portion of the tendon of insertion of the quadriceps femoris muscle. The patellar ligament is separated from the joint capsule by a large quantity of fat, the **infrapatellar fat pad** (corpus adiposum infrapatellare). A small synovial bursa is frequently located between the distal part of the ligament and the tuberosity of the tibia (bursa infrapatellaris).

The **lateral and medial patellar ligaments** (ligamentum patellae mediale et laterale) of the ox and the horse are ligamentous thickenings of the fibrous retinaculum. The lateral patellar ligament extends from the lateral part of the cranial surface of the patella to the lateral part of the tuberosity of the tibia. It is joined to the strong tendon of the biceps muscle of the thigh. The medial patellar ligament is attached proximally to the parapatellar fibrocartilage and ends on the medial aspect of the tibial tuberosity. The middle patellar ligament extends from the cranial part of the apex of the patella to the tuberosity of the tibia. A bursa is interposed between the ligament and the groove on the tuberosity of the tibia (bursa infrapatellaris distalis). A smaller bursa is present in the horse between the proximal part of the ligament and the apex of the patella (bursa infrapatellaris proximalis). The middle patellar ligament can be palpated just proximal to the tibial plateau.

In the horse the arrangement of the stifle joint provides a **locking mechanism,** which is an important part of the passive stay apparatus, by which one hindlimb may support a greater part of the body weight while the other limb is rested. The patella and the middle and medial patellar ligaments complete a binding loop. Thus the patella can be hooked over

the trochlea of the femur by contraction of the quadriceps muscle of the thigh in the resting position.

The joint capsule is very spacious with pouches under the tendon of insertion of the quadriceps muscle of the thigh proximally. Distally it communicates with the femorotibial joint cavity. The femoropatellar and the femorotibial joints share a common joint capsule with three sacs, one for the femoropatellar joint, one for the medial and one for the lateral femorotibial joint, all of which intercommunicate in the carnivores and the pig. In ruminants the two femorotibial sacs communicate with each other and the medial femorotibial joint communicates with the femoropatellar joint.

While in the horse the femoropatellar joint cavity communicates only sometimes with the lateral femorotibial joint and usually with the medial joint, there is no communication between the two femorotibial joints.

In carnivores the cavities of the femorotibial joints also include the **fabellae, sesamoid bones** within the tendon of origin of the gastrocnemius muscle. The lateral femorotibial joint capsule extends a pouch to form the proximal tibiofibular joint capsule.

Injection sites:

- **Dog:**
  The dog is placed in lateral recumbency with the joint of interest closest to the table in a slightly flexed position. The needle is inserted on the medial border of the patellar ligament, half way between the patella and the tibial tuberosity. The needle is advanced in a proximocaudal direction.
- **Pig:**
  The pig is placed in lateral recumbency. The needle is inserted just distal to the patella on the lateral border of the patellar ligament The needle is advanced in the horizontal plane directed caudomedially.
- **Ox:**
  Femoropatellar joint: A 12 cm needle is inserted between the medial and middle patellar ligament, 3 cm proximal to the tibial tuberosity and advanced proximally.
  Femorotibial joint: A 6 cm needle is inserted into the lateral pouch at the cranial or caudal border of the long digital extensor muscle between the tibial tuberosity and the lateral condyle and advanced proximally.
- **Horse:**
  To ensure anaesthesia of **all three joint compartments** each joint should be injected separately:
  The femoropatellar joint is injected with a 3 cm long needle in the weightbearing horse just distal to the apex of the patella between the middle and medial patellar ligament in a horizontal plane in a craniocaudal direction.
  The medial femorotibial joint is injected with a 3 cm long needle in the weightbearing horse 2 cm proximal to the medial condyle of the tibia, between the medial patellar and the medial collateral ligaments in a horizontal plane in a lateral direction.
  The lateral femorotibial joint is injected with a 8 cm long needle in the weightbearing horse just proximal to the tibial tuberosity cranial or caudal to the long digital extensor tendon in a medioproximal direction.

Tibiofibular joints

Due to the species specific reduction of the fibula, the tibiofibular joints vary accordingly.

In carnivores the fibula articulates with the tibia at each end by small and tight synovial joints, the **proximal and distal tibiofibular joints** (articulatio tibiofibularis proximalis et distalis) and forms a **syndesmosis** between the shafts of the two bones (membrana interossea cruris).

The proximal joint cavity communicates with the lateral **femorotibial joint** in all domestic mammals, except the horse, the distal one with the tarsocrural joint. In ruminants the head of the fibula is fused to the lateral condyle of the tibia and no proximal tibiofibular joint exists.

The **distal tibiofibular joint** is formed by the distal end of the fibula and the lateral malleolus.

In horses only the **proximal tibiofibular joint** exist, since the distal end of the fibula is fused to the tibia to form the lateral malleolus.

Pedal joints (articulationes pedis)

Tarsal joint or hock (articulatio tarsi)

The tarsal joint is a **composite joint** formed between the tibia and fibula, the tarsal bones and the metatarsal bones with four levels of articulation.

The **fibrous layer (membrana fibrosa)** of the joint capsule extends from the distal end of the crus to the proximal part of the metatarsus, covering the whole tarsus.

The **synovial layer (membrana synovialis)** forms four synovial sacs for the four levels of articulation:

- Tarsocrural joint (articulatio tarsocruralis),
- Proximal intertarsal joint
  (articulatio intertarsea proximalis),
- Distal intertarsal joint (articulatio intertarsea distalis),
- Tarsometatarsal joint (articulatio tarsometatarsea).

The **tarsocrural joint** is a cochlear joint formed between the trochlea of the talus and the distal end of the tibia and between the calcaneus and the distal end of the fibula or the lateral malleolus (ruminants). Since the distal end of the fibula is incorporated within the tibia in the horse, the tarsocrural joint is only formed between the tibia and the talus.

The joint capsule is spacious and communicates with the proximal intertarsal joint. It has three pouches, two plantar pouches, which extend proximal to the medial and lateral malleoli and a dorsal pouch, which extends under the medial tendon of the cranial tibial muscle (m. tibialis cranialis) (Fig. 4-68).

The proximal intertarsal joint (articulatio intertarsea proximalis) can be subdivided into the articulation between the talus and the calcaneus proximally and the **central** and **fourth tarsal bone distally** (articulatio talocalcaneocentralis and articulatio calcaneoquartalis). In carnivores lateral movement and rotation, as well as flexion and extension are possible. In ruminants only flexion and extension are possible and in the horse almost no movement occurs in the proximal intertarsal joint.

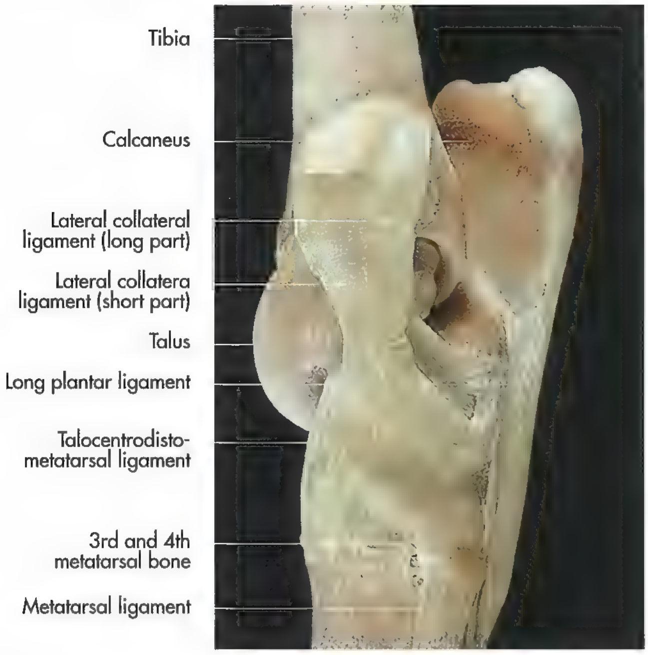

Fig. 4-62. Ligaments of the left tarsus of a horse (lateral aspect) (courtesy of Dr. R. Macher, Vienna).

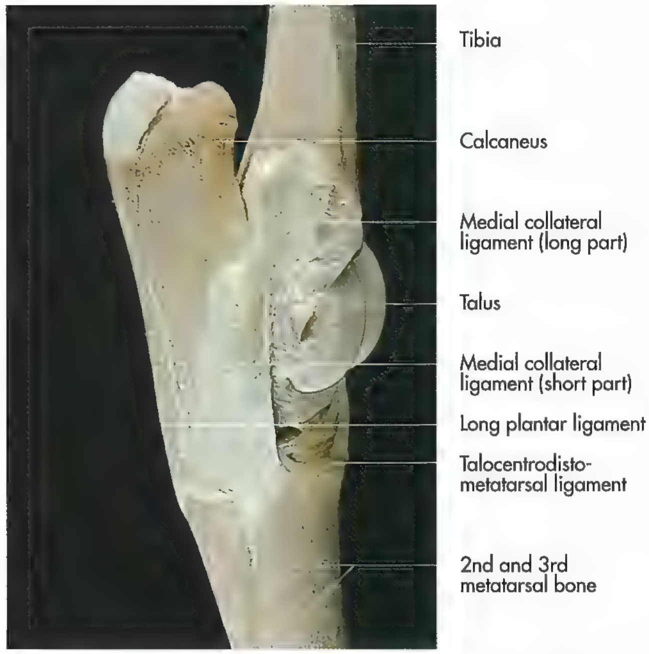

Fig. 4-63. Ligaments of the left tarsus of a horse (medial aspect) (courtesy of Dr. R. Macher, Vienna).

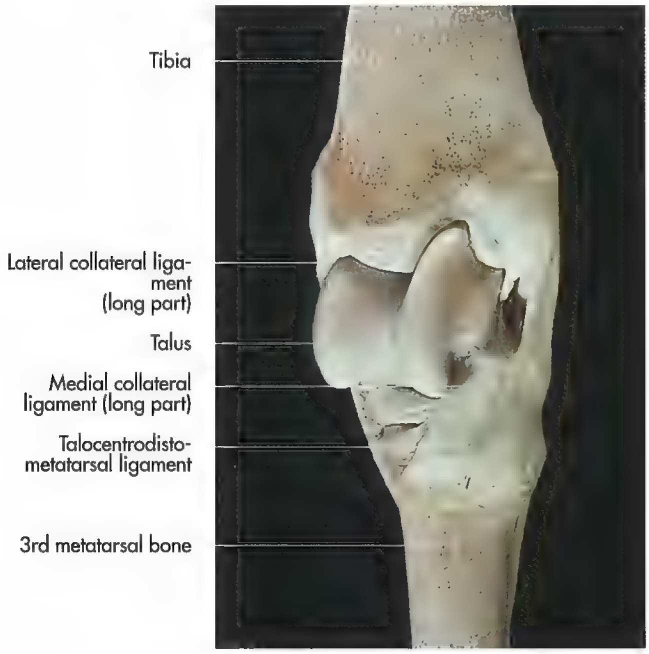

Fig. 4-64. Ligaments of the right tarsus of a horse (dorsal aspect) (courtesy of Dr. R. Macher, Vienna).

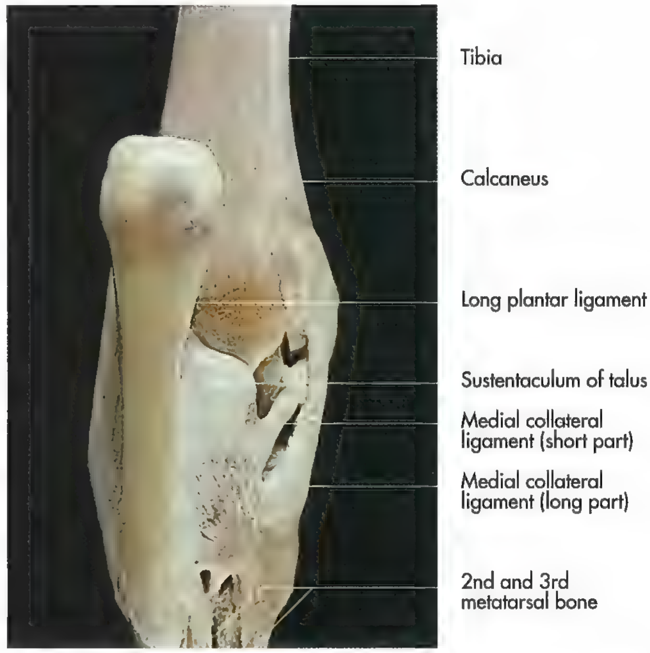

Fig. 4-65. Ligaments of the left tarsus of a horse (plantar aspect) (courtesy of Dr. R. Macher, Vienna).

The **distal intertarsal joint** (articulatio intertarsea distalis) is a rigid joint formed by the central tarsal bone proximally and the small tarsal bones distally.

The vertical joints between the bones of the same row are called intratarsal joints and are closely opposed and allow very little movement. The distal tarsal bones articulate with the metatarsal bones, forming the rigid **tarsometatarsal joints** (articulationes tarsometatarseae).

The ligaments of the tarsus comprise collateral ligaments, distal and proximal tarsal ligaments and fasciae.

- **Collateral ligaments** (ligamenta collateralia) can be further subdivided according to their length and location:
- **Long lateral collateral ligament** (ligamentum collaterale tarsi laterale longum) extends between the lateral malleolus and the base of the lateral metatarsal bones, attaching also to the lateral tarsal bones along its course.

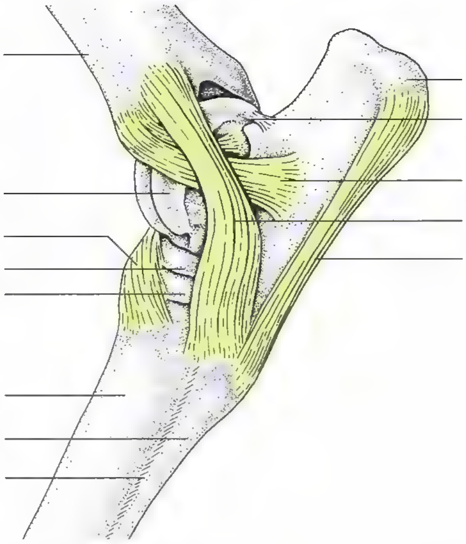

Fig. 4-66. Ligaments of the left tarsus of the horse (schematic, lateral aspect) (Červeny, 1980).

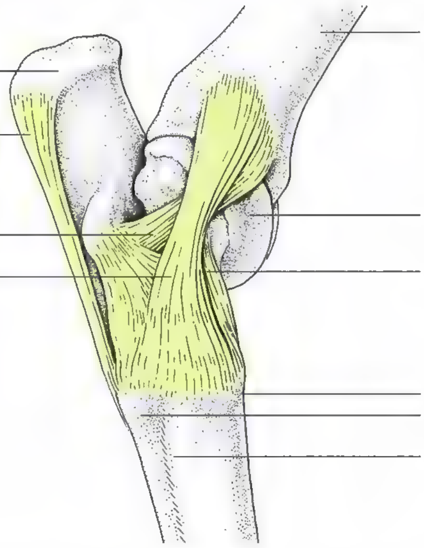

Fig. 4-67. Ligaments of the left tarsus of the horse (schematic, medial aspect) (Červeny, 1980).

- **Short lateral collateral ligament** (ligamentum collaterale tarsi laterale breve) runs deep to the long lateral collateral ligament. It arises from the lateral malleolus and attaches with one branch to the calcaneus and one branch to the talus.
- **Long medial collateral ligament** (ligamentum collaterale tarsi mediale longum) extends between the medial malleolus and the base of the medial metatarsal bones, attaching also to the medial tarsal bones along its course.
- **Short medial collateral ligament** (ligamentum collaterale tarsi mediale breve) arises from the medial malleolus, deep to the long one and divides into two branches, one of which attaches to the talus and one to the calcaneus. In carnivores and ruminants an additional branch extends to the medial metatarsal bones.
- **Various ligaments** bridge the joint spaces in vertical, horizontal and oblique direction on the dorsal and plantar aspect of the hock. The more prominent ones are:

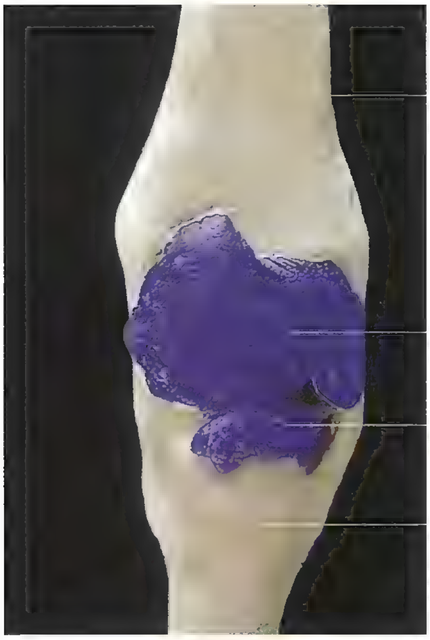

Fig. 4-68. Acrylic cast of the left tarsus of a horse (dorsal aspect) (courtesy of Dr. Margit Teufel, Vienna).

- **Dorsal tarsal ligament** (ligamentum tarsi dorsale seu ligamentum talocentrodistometatarseum), a triangular sheath, which spreads out between the medial aspect of the talus and the central and third tarsal bones and the third and fourth metatarsal bones.
- **Long plantar ligament** (ligamentum plantare longum): A very strong, flat band on the plantar aspect of the hock, extending between the distal calcaneus in carnivores or the tuber calcanei in the other domestic species and the central and fourth tarsal bones and the proximal end of the third and fourth metatarsal bones.
- Various **short ligaments** bridge the joint spaces between the adjacent bones of the same level or the neighbouring level (ligamenta tarsi interossea).
- Several strong **fascia** (retinacula) are formed to keep tendons in place and several blood vessels and nerves are embedded in this fascia. They are partly fused to the joint capsule.

Injection sites:

- **Dog:** The dog is put in lateral recumbency and the hock extended. The needle is inserted just distal to the distal end of the fibula and dorsal to the palpable tendon of the long peroneal muscle. The needle is advanced in a distoplantar direction.
- **Pig:** The tarsocrural joint is injected by inserting the needle on the dorsal border of the lateral malleolus in a horizontal plane in a medial direction.
- **Ox:** A 6 cm needle is inserted between the lateral collateral ligament and the tendon of insertion of the cranial tibial muscle and advanced horizontally.
- **Horse:** The tarsocrural and proximal intertarsal joints are injected from the mediodorsal aspect with a 3 cm needle in the weightbearing horse. The needle is inserted into the palpable depression just distal to the medial malleolus in a horizontal plane in a lateral direction. Care has to be taken not to puncture the cranial branch of the medial saphenous vein.

The distal intertarsal joint is injected from the medial aspect with a 3 cm needle in the weightbearing horse. A small depression is often palpable at the level of the distal part of the cunean tendon and along an imaginary line between the palpable distal tubercle of the talus and the proximal ends of the second and third metatarsal bones. The needle is inserted in a horizontal plane in a slightly caudal direction.

The tarsometatarsal joint is injected from the lateral aspect with a 2 cm needle in the weightbearing horse. The needle is inserted 1 cm proximal to the head of the fourth metatarsal bone in a dorsal and slightly distomedial direction.

Metatarsal and phalangeal joints

The joints of the metatarsus and digits are similar to the corresponding joints of the thoracic limb.

Fasciae of the pelvis and the pelvic limb

The inner fascia of the trunk, which is termed the **transverse fasia** (fascia transversalis) in the abdomen, is continuous with the **iliac fascia** (fascia iliaca) of the pelvis. The iliac fascia forms a major part of the **muscular lacuna** (lacuna muscularis) for the passage of the iliopsoas muscle and, craniomedial to it the **vascular lacuna** (lacuna vasculorum), through which the femoral artery and vein and the saphenous nerve pass. Caudally it is continuous with the inguinal ligament and the fascia of the **pelvic diaphragm** (fascia diaphragmatis pelvis).

The muscles of the hindlimb are superficially covered by several layers of extensive fascia, which send multiple septa between the muscles. In the gluteal region it is termed the **gluteal fascia** (fascia glutaea), on the medial side of the femur it is termed the **femoral fascia** (fascia femoralis) and on the lateral aspect of the femur it is termed the **fascia lata.** Distally these fasciae continue as the **fascia of the stifle joint** (fascia genus) and the **crural fascia** (fascia cruris) (Fig. 4-75). The fasciae are strenghthened to form the retinacula of the stifle. The crural fascia of the tarsus holds the tendons as they pass over these joints.

Muscles of the pelvic limb (musculi membri pelvini)

The pelvic limb musculature includes both the **intrinsic muscules of the limb** and the **girdle musculature.**

Girdle musculature of the pelvic limb

The girdle muscles arise from the ventral aspect of the lumbar vertebrae and insert on the pelvis or the femur. The musculature of the pelvic girdle, also termed the sublumbar muscles, comprises:

Fig. 4-69. Girdle musculature of the pelvic limb of a dog (ventral aspect).

- Smaller psoas muscle (m. psoas minor),
- Iliopsoas muscle (m. iliopsoas) and
- Quadrate lumbar muscle (m. quadratus lumborum).

These muscles control dorsiflexion and ventriflexion of the spine and stabilize the vertebral column and the pelvis during progression. Because of the limited mobility of the sacroiliac articulation, these muscles are weaker than their equivalent muscles of the thoracic limb (Fig. 4-69, 70 and Tab. 4-5).

The **smaller psoas muscle** arises from the ventral aspect of the second or third caudal thoracic vertebrae and the fourth or fifth cranial lumbar vertebrae and inserts by the means of a strong tendon to the psoas tubercle of the femoral shaft (Fig. 4-70). In carnivores the smaller psoas muscle is, like the other sublumbar muscles, a strong fleshy muscle. The muscle bellies of each side, border the tendons of origin of the diaphragmatic crura. The flat tendon of insertion is fused to the iliac fascia and ends on the arcuate line of the ilium extending to the iliopubic eminence. In ruminants and the horse the muscle is marked by multiple tendinous intersections.

The smaller psoas muscle muscle steepens the pelvis when the vertebral column is fixed and flexes the vertebral column during the stance phase of movement.

The **iliopsoas muscle** is the strongest muscle of the pelvic girdle. It can be divided into the lumbar and iliac parts in all domestic mammals, except in carnivores where both portions are firmly fused.

- Greater psoas muscle (m. psoas major) representing the lumbar portion and
- Iliac muscle (m. iliacus) representing the iliac portion.

The **greater psoas muscle** originates from the bodies and transverse processes of the lumbar vertebrae, the last two thoracic vertebrae and the ribs and is lateral to the small lumbar muscles (Fig. 4-70). It lies ventral to the quadrate lumbar muscle and dorsal to the smaller psoas muscles. It inserts on the lesser trochanter of the femur after its incorporation with the iliac muscle.

The **iliac muscle** originates on the wing and the shaft of the ilium and inserts on the lesser trochanter of the femur by the common tendon of the iliopsoas muscle. Before inserting the iliopsoas muscle passes through the **muscular lacuna** (lacuna musculorum). This opening is formed caudal to the abdominal wall by the os coxae laterally and caudally, the rectus abdominis muscle medially and the the iliac fascia cranially.

In ruminants and the horse the iliac muscle is a strong fleshy muscle, which is flat in cross-section cranially, but more rounded caudally. It arises with two heads, the stronger lateral head originates from the wing of the ilium, the smaller medial one from its shaft. The two parts enclose the greater psoas muscle, with which they unite to form the common tendon of insertion on the lesser trochanter of the femur.

The iliopsoas muscles advance the pelvic limb by flexing the hip joint and by outward rotation of the stifle joint. When the limb is fixed, in the stance phase of movement, the iliopsoas muscles flex the vertebral column. When the the limb is extended the muscle causes the trunk to be drawn caudally.

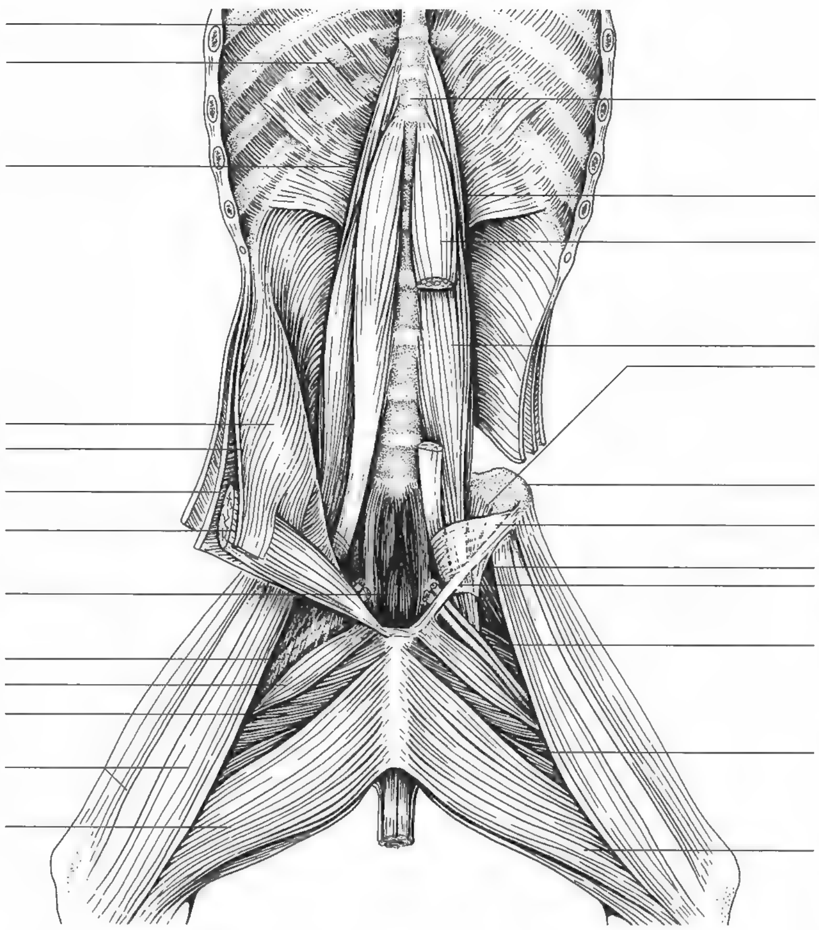

Fig. 4-70. Girdle musculature, medial muscles of the thigh of the pelvic limb and abdominal muscles of the dog (schematic, ventral aspect), (Ellenberger and Baum, 1943).

The **quadrate lumbar muscle** originates from the ventral surfaces of the transverse processes of the lumbar vertebrae and the proximal ends of the ribs and inserts on the ventral surface of the wings of the sacrum and ilium (Fig. 4-70).

In carnivores this muscle is stronger than in the other domestic species and has a thoracic part and a lumbar part. The thoracic part has several orgins arising from each of the bodies of the last three thoracic vertebrae and inserts on the transverse processes of the cranial lumbar vertebrae. The lumbar part extends to and inserts on the ventral border of the sacrum and iliac wing.

In ruminants and the horse, the quadrate lumbar muscle is a thin, tendinous muscle, which originates from the proximal end of the last rib and the transverse processes of the cranial lumbar vertebrae, and inserts on the transverse processes of the caudal lumbar vertebrae and the wing of the sacrum.

The quadrate lumbar muscle stabilises the lumbar vertebral column. In animals where ventriflexion and dorsiflexion are possible, such as carnivores and the pig, it also causes ventriflexion of the sacroiliac joint.

Intrinsic musculature of the pelvic limb

The intrinsic muscles of the hindlimb provide the forward impetus to locomotion. The power developed by these muscles it transferred to the trunk through the coxofemoral and sacroiliac joints which are supported by the muscles of the hindlimb. Thus, the intrinsic musculature of the pelvic limb is further developed and shows more complex structure than the corresponding musculature of the thoracic limb. The muscle bellies of the proximal muscles are large and model the contour of the croup and thigh. The long tendinous muscles of the distal limb, similar to the forelimb, cause flexion and extension of the tarsal and digital joints (Fig. 4-71 to 74).

The **intrinsic musculature** comprises:

- Muscles of the hip,
- Muscles of the stifle,
- Muscles of the tarsus and
- Muscles of the digits.

The muscles of the hip are particularly large in the horse, where they round the contours of the croup in a distinctive

Tab. 4-5. Girdle musculature of the pelvic limb.

Name Innervation	Origin	Insertion	Action
Smaller psoas muscle Dog: Ventral branches of 4th–5th lumbar nerves Horse: Intercostal nerves, ventral branches of lumbar, nerves, genitofemoral nerve, femoral nerve	Last thoracic vertebrae, 1st–4th lumbar vertebrae	Arcuate line of ilium	Fixator and flexor of the lumbar vertebral column
Iliopsoas muscle **Greater psoas muscle** Dog: Ventral branches of the 4th–5th lumbar nerves Horse: Intercostal nerves, femoral nerve	Last thoracic vertebra, lumbar vertebrae	Lesser trochanter of femur	Flexor of the hip joint, draws hindlimb forwards
Iliac muscle Lumbar nerves, genitofemoral nerve, femoral nerve	Iliac fascia, wing of ilium	Lesser trochanter of femur	
Quadrate lumbar muscle Dog: Ventral branches of 4th–5th lumbar nerves Horse: Intercostal nerves, ventral branches of lumbar, nerves, genitofemoral nerve, femoral nerve	Ventral on the transverse processes of the lumbar vertebrae	Transverse processes of the lumbar vertebrae, wing of sacrum, wing of ilium	Fixator of the lumbar vertebral column

Tab. 4-6. Rump muscles.

Name Innervation	Origin	Insertion	Action
Superficial gluteal muscle Caudal gluteal nerve	Gluteal fascia and sacrum	Greater and third trochanter	Extensor and flexor of the hip joint
Gluteofemoral muscle Caudal gluteal nerve	2nd–4th caudal vertebrae	Fascia lata, patella	Draws limb outwards and backwards, draws the tail to the side
Middle gluteal muscle Cranial gluteal nerve	Ilial wing, sacrum and 1st lumbar vertebra	Greater trochanter	Extensor of the hip joint, draws limb outwards and backwards
Piriform muscle Cranial gluteal nerve	Ventral surface and lateral side of sacrum	Greater trochanter	Extensor of the hip joint, draws limb outwards and backwards
Deep gluteal muscle Cranial gluteal nerve	Ischiatic spine	Greater trochanter	Draws limb outwards and backwards
Tensor muscle of fascia lata Cranial gluteal nerve	Coxal tuberosity	Fascia lata	Draws limb forwards, tensor of the fascia

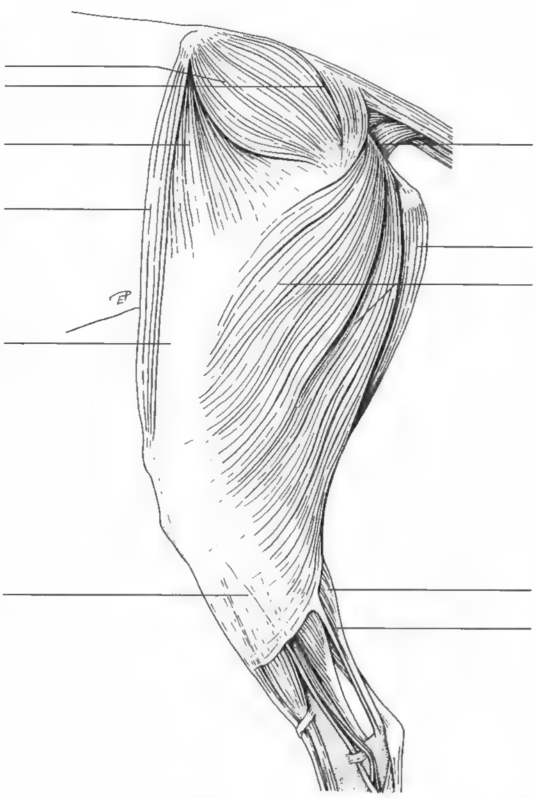

Fig. 4-71. Superficial muscles of the pelvic limb of the dog (schematic, lateral aspect) (Schaller, 1992).

fashion. Their primary function is to extend the hip joint, but some also act as extensors of the stifle and the tarsus. These muscles are grouped according to their position.

The **rump muscles** comprises:

- Hamstring muscles,
- Inner pelvic muscles and
- Medial muscles of the thigh.

Rump muscles

The muscles of the rump lie over the lateral and caudal part of the pelvic wall. They extend between the ilium and the thigh and are arranged in several layers (Fig. 4-71 to 76 and Table 4-6). This group comprises:

- Superficial gluteal muscle (m gluteus superficialis),
- Gluteofemoral muscle (m gluteofemoralis),
- Middle gluteal muscle (m gluteus medius),
- Piriform muscle (m. piriformis),
- Deep gluteal muscle (m. gluteus profundus) and
- Tensor muscle of the fascia lata (m. tensor fasciae latae).

The **superficial gluteal muscle** shows species specific variation. The muscle is only present as an isolated muscle in the carnivores, whereas in other domestic species it is fused to neighbouring muscles (Fig. 4-71 and 72).

In carnivores the superficial gluteal muscle is a rectangular muscle plate, extending between the sacrum, the first caudal vertebrae and the ilium proximally and the major trochanter distally. It originates from the gluteal fascia, the lateral part of the sacrum, the sacral tuber of the ilium, the first caudal vertebra and the sacrotuberous ligament. Its fibres converge to form a tendon, which runs caudodistally over the greater trochanter and inserts distal to it.

In the pig the superficial gluteal muscle has two portions, a smaller superficial and a larger deep portion. The superficial part is further subdivided into a cranial portion, which takes origin from the gluteal fascia and fuses with the tensor muscle of the fascia lata and a caudal portion, which originates cranial to the biceps muscle of the thigh and radiates into the fascia lata. The deep portion takes its origin from the sacrum and the first caudal vertebrae and joins the biceps muscle to form the gluteobiceps muscle.

In small ruminants the superficial gluteal muscle is partly fused with the biceps muscle of the thigh and in the ox it is completely fused and is therefore termed the **gluteobiceps muscle.**

In the horse the superficial gluteal muscle originates from the gluteal fascia and covers the middle guteal muscle. It unites with the tensor muscle of the fascia lata distal to the hip. Having passed over the greater trochanter, their common tendon of insertion attaches on the third trochanter and radiates into the femoral fascia (Fig. 4-72 and 76). A synovial

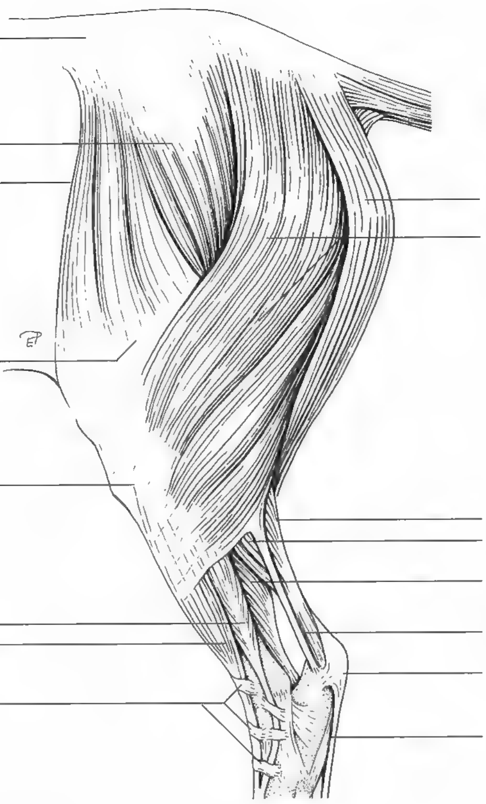

Fig. 4-72. Superficial muscles of the pelvic limb of the horse (lateral aspect, schematic) (Ghetie, 1955).

bursa is interposed between its tendon of insertion and the third trochanter.

The superficial gluteal muscle extends the hip joint. It also retracts the limb and supports outward rotation.

The **gluteofemoral muscle** exists only in the cat. It is located as a narrow muscle band between the superficial gluteal muscle and the biceps muscle of the thigh. It originates from the second to fourth caudal vertebra and inserts on the lateral aspect of the patella and the fascia lata by means of an aponeurosis. Its function is retraction and abduction of the limb and extension of the hip. It is also responsible for lateral movements of the tail, when the limb is in a fixed position.

The **middle gluteal muscle** is the largest muscle of this group except in the ox, where it is a flat muscle, responsible for the contour of the croup in this species (Fig. 4-75). It lies on the lateral surface of the ilium and is covered by the superficial gluteal muscle, the gluteal fascia and partly by the thoracolumbar fascia (Fig. 4-71).

In the dog, this muscle takes origin from the gluteal surface of the ilium between the iliac crest and the gluteal line. In the horse and the pig it also originates from the first lumbar vertebra, the aponeurosis of the longissimus muscle of the loins, the sacrum and the broad sacrotuberous ligament. In the ox the muscle is flat at its origin, thus the iliac crest is palpable. In ungulates the middle gluteal muscle fuses caudally with the piriformis muscle. The middle gluteal muscle is divided into a deep and superficial part by a tendinous sheet. The superficial portion inserts with a short tendon on the greater trochanter, its tendinous deep portion inserts with one tendon on the greater trochanter and a second tendon passes further distally beneath the lateral vastus muscle and ends distal and medial to the greater trochanter in the ox and on the intertochanteric crest in the horse. Both tendons are protected by a synovial bursa on the site of their insertion. The deep portion is termed the **accessory gluteal muscle.**

The middle gluteal muscle is the most powerful extensor of the hip and retractor and abductor of the limb. In the horse the strong lumbar portion delivers the power of the hindlimb directly to the trunk, thus has a major role when the horse rears up.

The **piriform muscle** is fused to the middle gluteal muscle in all domestic species, except the carnivores. In carnivores the piriform muscle lies caudal and medial to the middle gluteal muscle and is covered by the superficial gluteal muscle. It arises from the last sacral vertebra and the sacrotuberous ligament, passes over the greater trochanter and inserts just distal to it on the lateral surface of the femur. In the horse it is fused to the middle gluteal muscle proximally, but passes over the greater trochanter with a separate tendon and inserts on the caudal aspect of the femur. It is an extensor of the hip and an abductor of the limb.

The **deep gluteal muscle** is a short, strong muscle, marked by multiple tendinous intersections. It is the deepest muscle of the gluteal group and lies directly over the hip joint (Fig. 4-84). It originates from the lateral surface of the ilial

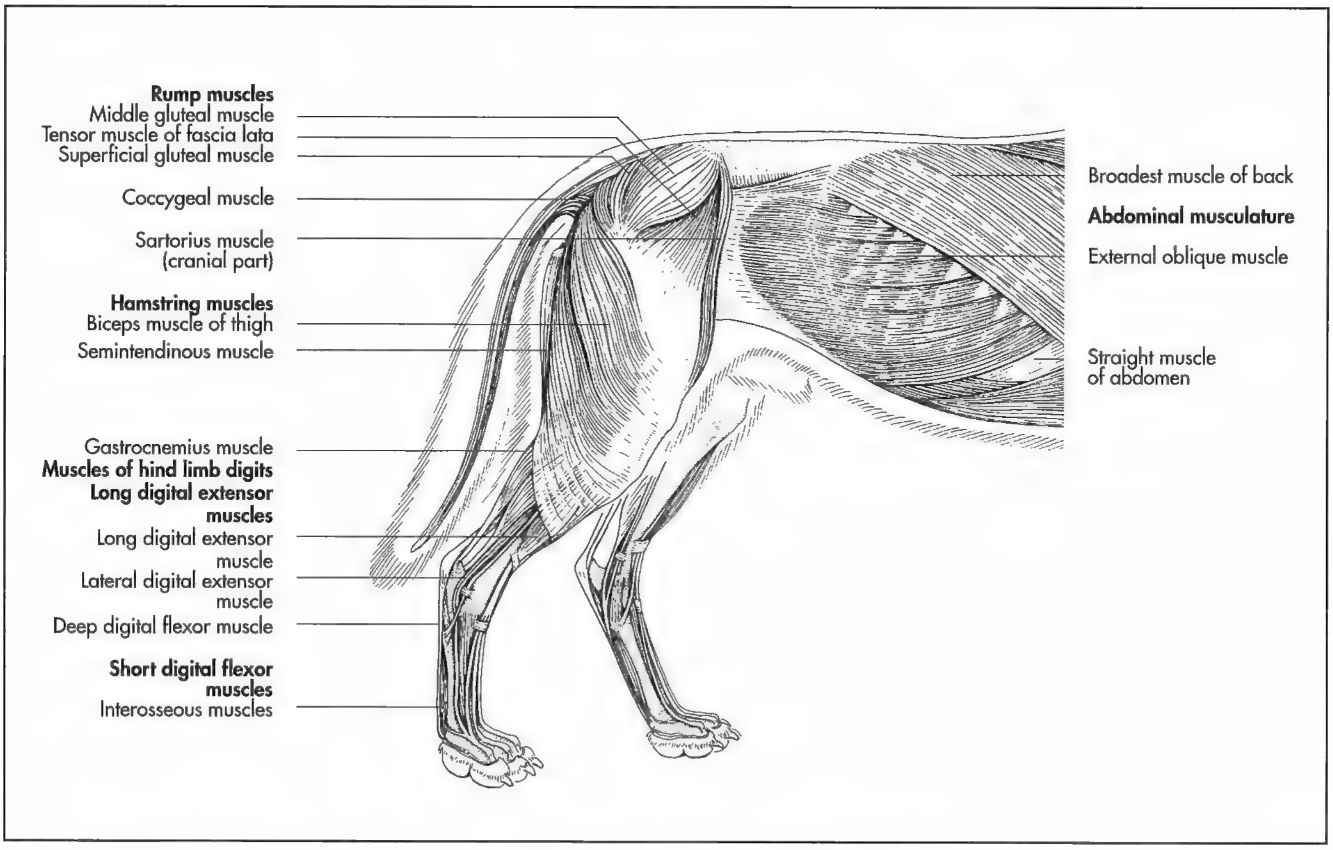

Fig. 4-73. Abdominal muscles and superficial musculature of the pelvic limb of the dog (schematic).

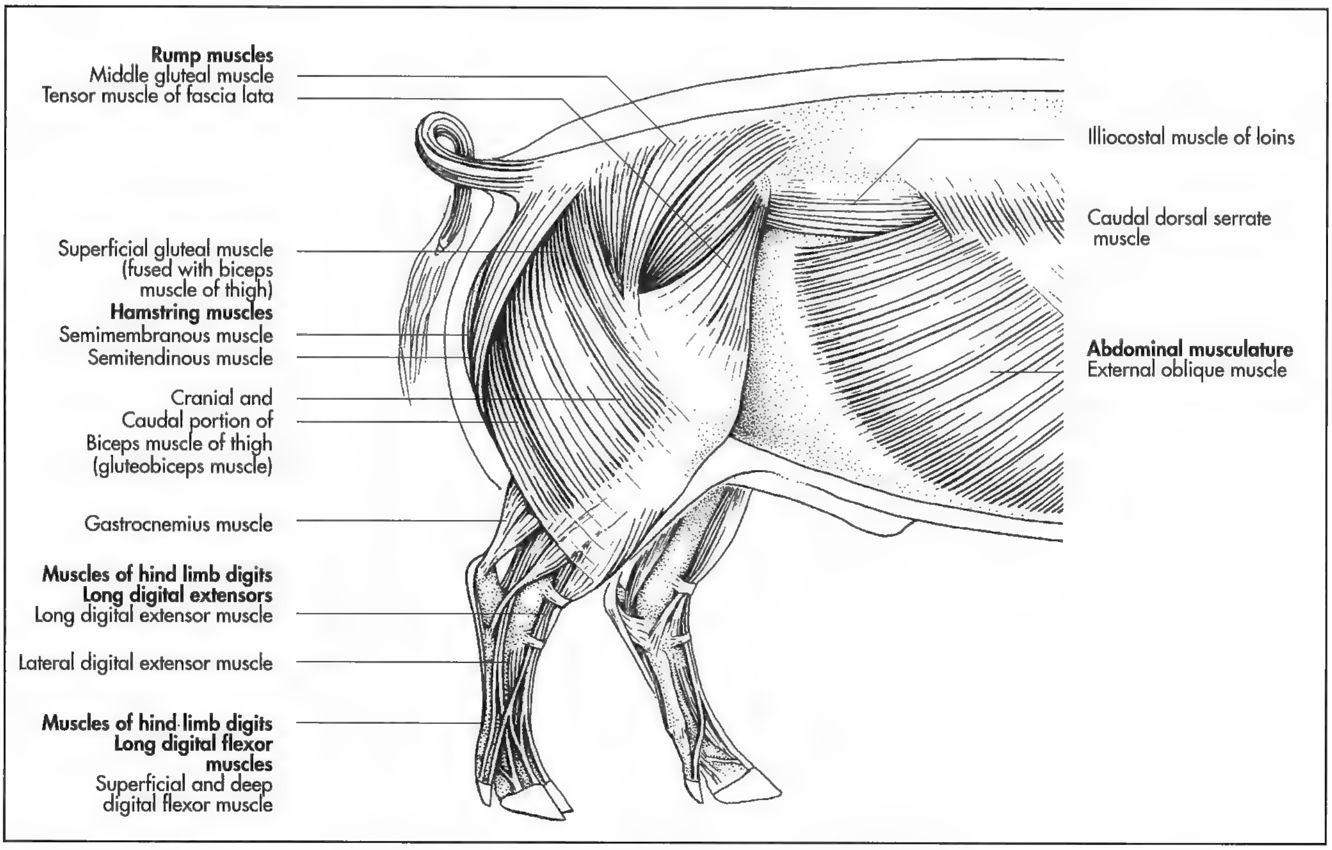

Fig. 4-74. Abdominal muscles and superficial musculature of the pelvic limb of the pig (schematic).

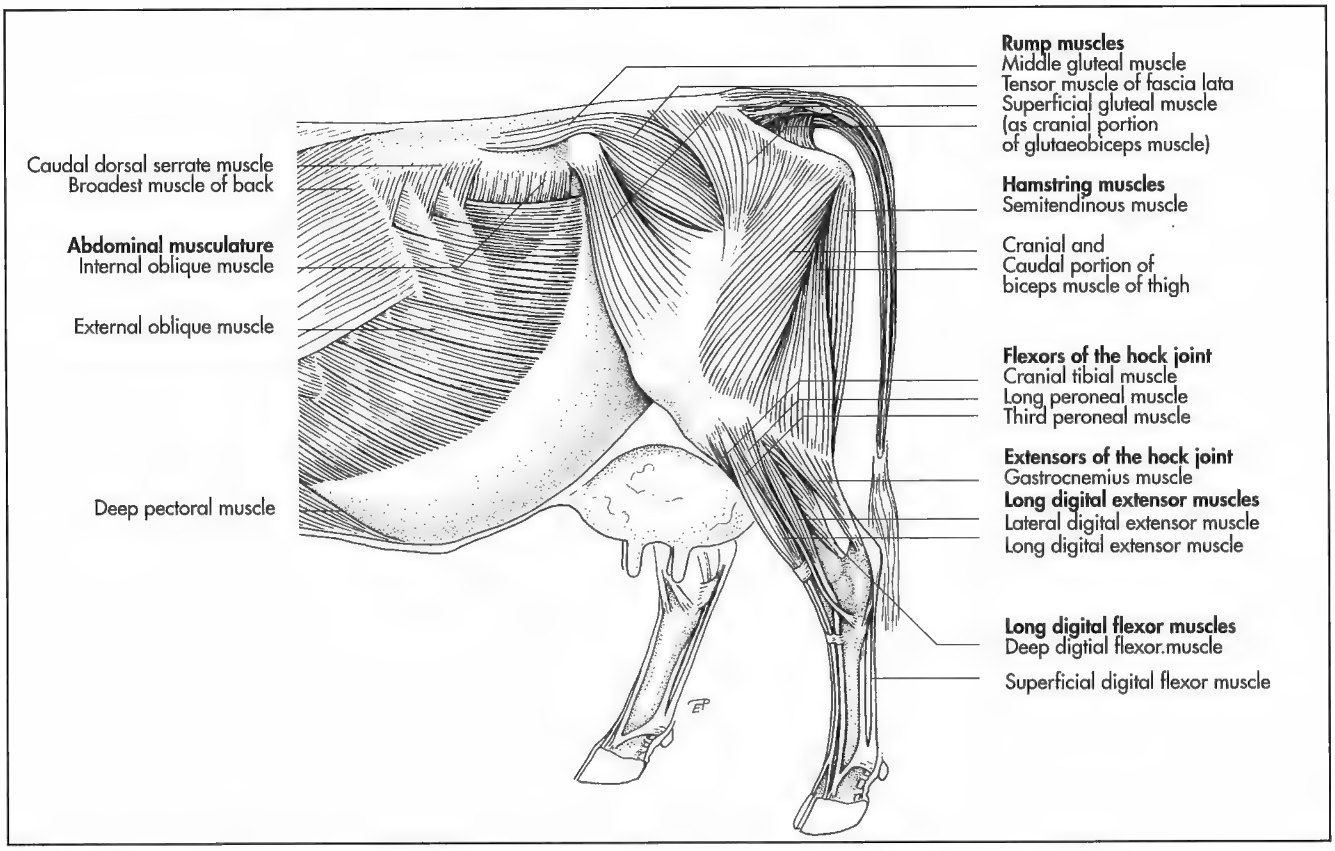

Fig. 4-75. Abdominal muscles and superficial musculature of the pelvic limb of the ox (schematic).

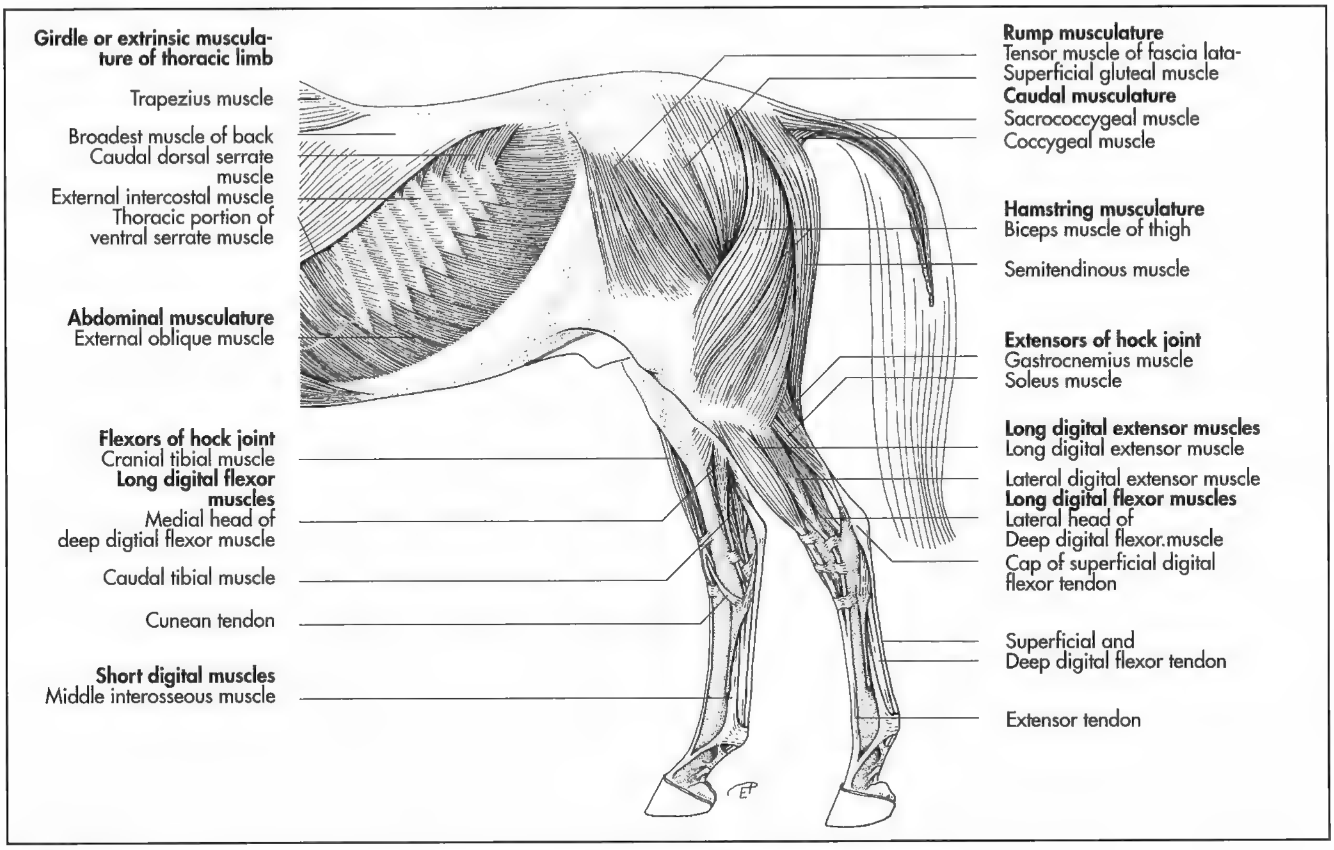

Fig. 4-76. Abdominal muscles and superficial musculature of the pelvic limb of the horse (schematic).

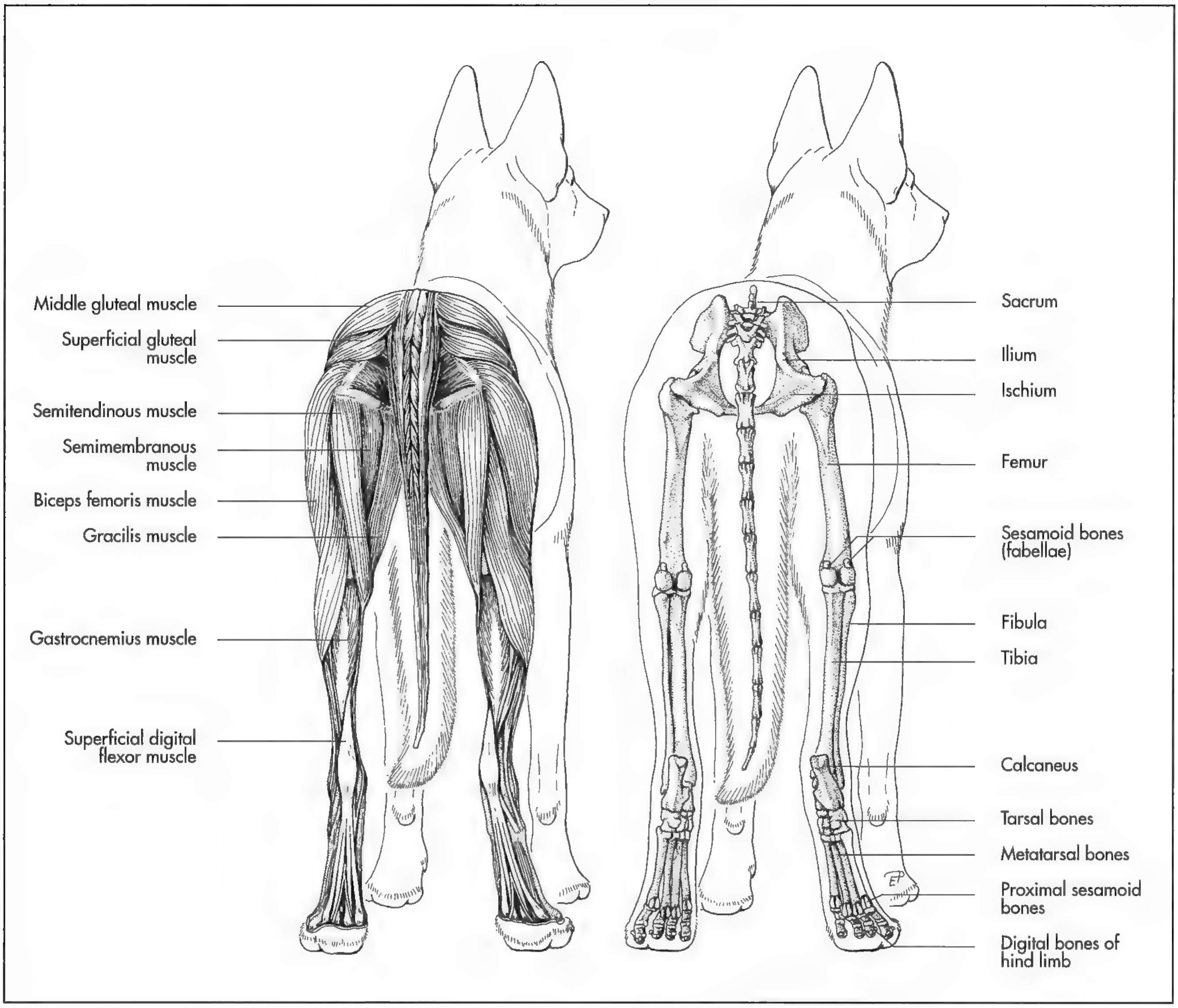

Fig. 4-77. Superficial muscles and skeleton of the pelvic limb of the dog (schematic, caudal aspect).

shaft, near the iliac spine, and, in ruminants, the broad sacrotuberous ligament. It inserts with a short strong tendon on the greater trochanter or, in ruminants, distal to it on the craniolateral aspect of the femur. It supports the middle gluteal muscle in abduction of the limb.

The **tensor muscle of the fascia lata** is the most cranial of the rump muscles. It fills the triangle between the lateral angle of the ilium and the stifle joint and models the cranial border of the thigh. In carnivores it originates from the ventral part of the iliac spine and the aponeurosis of the middle gluteal muscle. It fans out and radiates with three moderately distinct parts into the fascia lata with which it continues distally to the patella (Fig. 4-71). It is bordered cranially by the sartorius muscle and dorsally by the middle gluteal muscle.

In ruminants and the horse the tensor muscle of the fascia lata originates from the coxal tuberosity and extends distally on the cranial border of the quadriceps muscle of the thigh. It combines with the fascia lata and thus indirectly inserts to the patella, the lateral patellar ligament and the cranial border of the tibia. A caudodorsal detachment joins the superficial gluteal muscle, which in turn attaches to the greater trochanter of the femur (Fig. 4-72). It tenses the fascia lata, thus flexing the hip and extending the stifle. It also advances the limb during the swing phase of locomotion.

Hamstring muscles

The hamstring group of muscles cover the caudal part of the thigh. They extend from the ischium to the tibia and their tendinous components continue as part of the **common calcanean tendon** (tendo calcaneus communis) to the calcaneus (Fig. 4-77, 78 and Table 4-7). These muscles are multiarticular, spanning the hip and the stifle joints, and some the tarsus. In ungulates some of the hamstring muscles have vertebral heads, which arise from the sacral and caudal vertebrae in addition to those heads arising from the pelvis. These vertebral heads are best developed

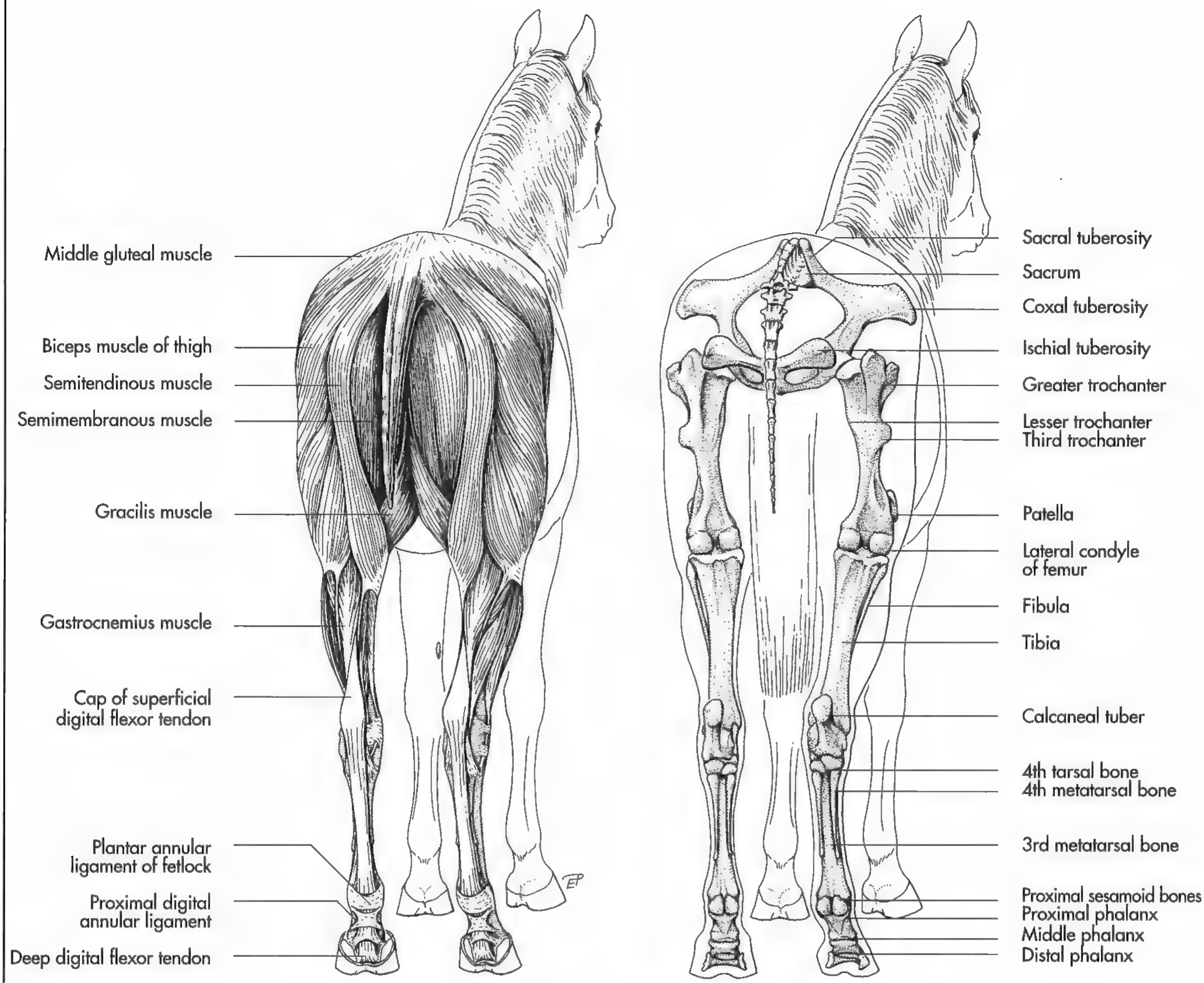

Fig. 4-78. Superficial muscles and skeleton of the pelvic limb of the horse (schematic, caudal aspect).

in the horse and account for the species specific rounded appearance of the rump. This group of muscles comprises:

- Biceps muscle of the thigh (m. biceps femoris),
- Abductor muscle of the thigh (m. abductor cruris caudalis),
- Semimembranous muscle (m. semimembranosus) and
- Semitendinous muscle (m. semitendinosus).

The **biceps muscle of the thigh** is the largest and most lateral of the caudal muscles of the thigh. It is superficial, covered only by the fascia and skin. It consists of a strong cranial part, which arises from the sacrum and the sacrotuberous ligament (vertebral head) and a smaller caudal part, which arises from the ischium (pelvic head). In ruminants and the pig the vertebral head is firmly fused to the superficial gluteal muscle, forming the gluteobiceps muscle. The united muscle belly splits into two tendons of insertion in carnivores, the pig and ruminants and three tendons of insertion in the horse. These tendons radiate into the fascia lata, the fascia of the stifle and the crural fascia with which they attach to the patella, ligaments of the stifle and the tibia. An additional **tarsal tendon** is detached for insertion on the calcaneus.

In the dog the biceps muscle of the thigh originates with a cranial superficial head from the sacrotuberous ligament and with a smaller caudal head from the lateral angle of the ischial tuberosity (Fig. 4-77). The superficial head forms the cranial part of the muscle, the smaller deep portion emerges on the caudal aspect of the buttock. Both muscle bellies broaden distally and unite by means of an aponeurosis with the crural fascia and the fascia of the stifle. Through this fascia they insert to the patella, the patellar ligament and the tuberosity of the tibia. A distinct distal tendon of the main muscle belly passes distally under the abductor muscle of the thigh and along the gastrocnemius muscle. It curves in front of the main part of the calcaneal tendon to insert on the calcaneal tuberosity after combining with a similar tendon from the semitendinous muscle.

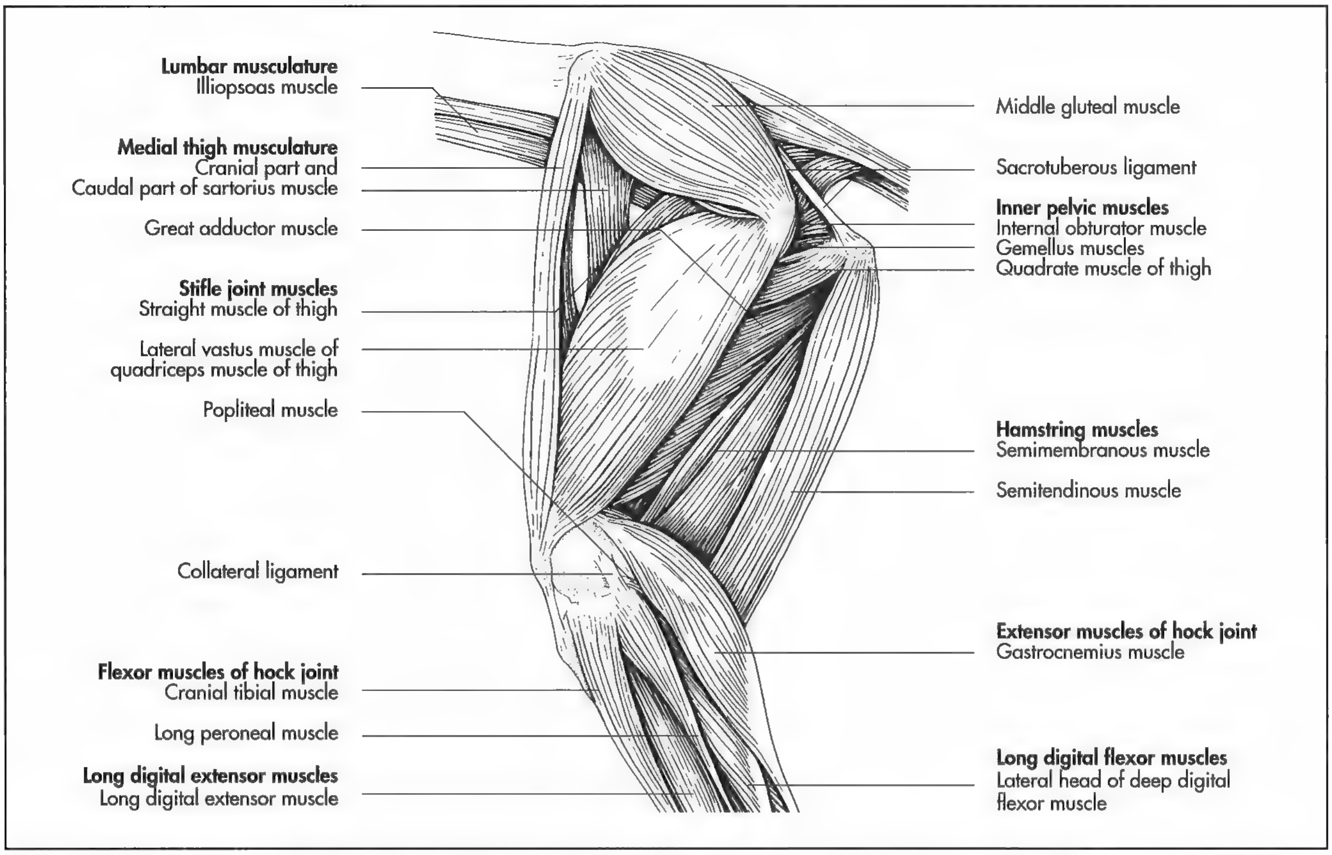

Fig. 4-79. Deep muscles of the pelvic limb of the dog (schematic, lateral aspect) (Anderson and Anderson, 1994).

The two heads of the biceps muscle of the thigh are less defined in ruminants and pigs than in the other domestic species. The vertebral head arises from the caudal sacral vertebrae, the broad sacrotuberous ligament and the ischial tuberosity and is fused with the superficial gluteal muscle forming the **gluteobiceps muscle.** The caudal pelvic head originates from the ventrolateral aspect of the ischium extending from the ischiatic tuberosity to the obturator foramen. At the mid-tibia it divides into two insertions. The cranial of which attaches by way of the fascia lata and crural fascia to the patella, lateral patellar ligament and the tibial tuberosity. The cranial part froms the tarsal tendon, which inserts on the calcaneal tuberosity. A synovial bursa is interposed between the tarsal tendon and the lateral femoral condyle, which is of clinical significance when inflamed.

In the horse the two heads of origin are well defined (Fig. 4-78). The vertebral head arises from the spinous and transverse processes of the three sacral vertebrae, from the caudal border of the broad sacrotuberous ligament and the ischial tuberosity. The smaller pelvic head originates from the ventral aspect and the caudal rim of the ischium. They unite and divide again distally into three parts, a cranial, middle and caudal branch, which form extensive aponeuroses. The cranial branch inserts on the caudal surface of the femur, just distal to the third trochanter and on the patella and lateral patellar ligament. The middle branch attaches on the crural fascia, the lateral patellar ligament and the cranial aspect of the tibia. The caudal branch radiates into the crural fascia and forms the strong tarsal tendon, which runs distally beneath the common cunean tendon and inserts to the calcaneus after it has combined with a similar detachment from the semitendinosus muscle.

Since the muscle is composed of several parts and has several points of insertion, the action is somewhat complex. The general action is to extend and abduct the limb. The cranial vertebral part extends the hip and the stifle, whereas the caudal pelvic head also extends the hip, but flexes the stifle. Through its attachment as the tarsal tendon it also assists in extending the tarsus.

The strap-like **abductor muscle of the thigh** is only present in carnivores. It originates from the sacrotuberous ligaments, extends distally under the caudal edge of the biceps muscle of the thigh and inserts on the crural fascia. It assists the biceps muscle of the thigh in the abduction of the limb.

The **semitendinous muscle** is a large fleshy muscle, which forms a large part of the caudal contour of the thigh (Fig. 4-77 and 78). It orginates from the ventral surface of the ischial tuberosity **(pelvic head)** and inserts together with the tendons of the gracilis and sartorius muscles on the cranial margin of the tibia and with a separate tendon of insertion on the calcaneal tuberosity. There is an additional **vertebral head** in horses and pigs, originating from the spinous and transverse processes of the sacrum, first caudal vertebrae and the broad sacrotuberous ligament.

In carnivores the semitendinous muscle originates from the caudal and ventrolateral part of ischial tuberosity between the

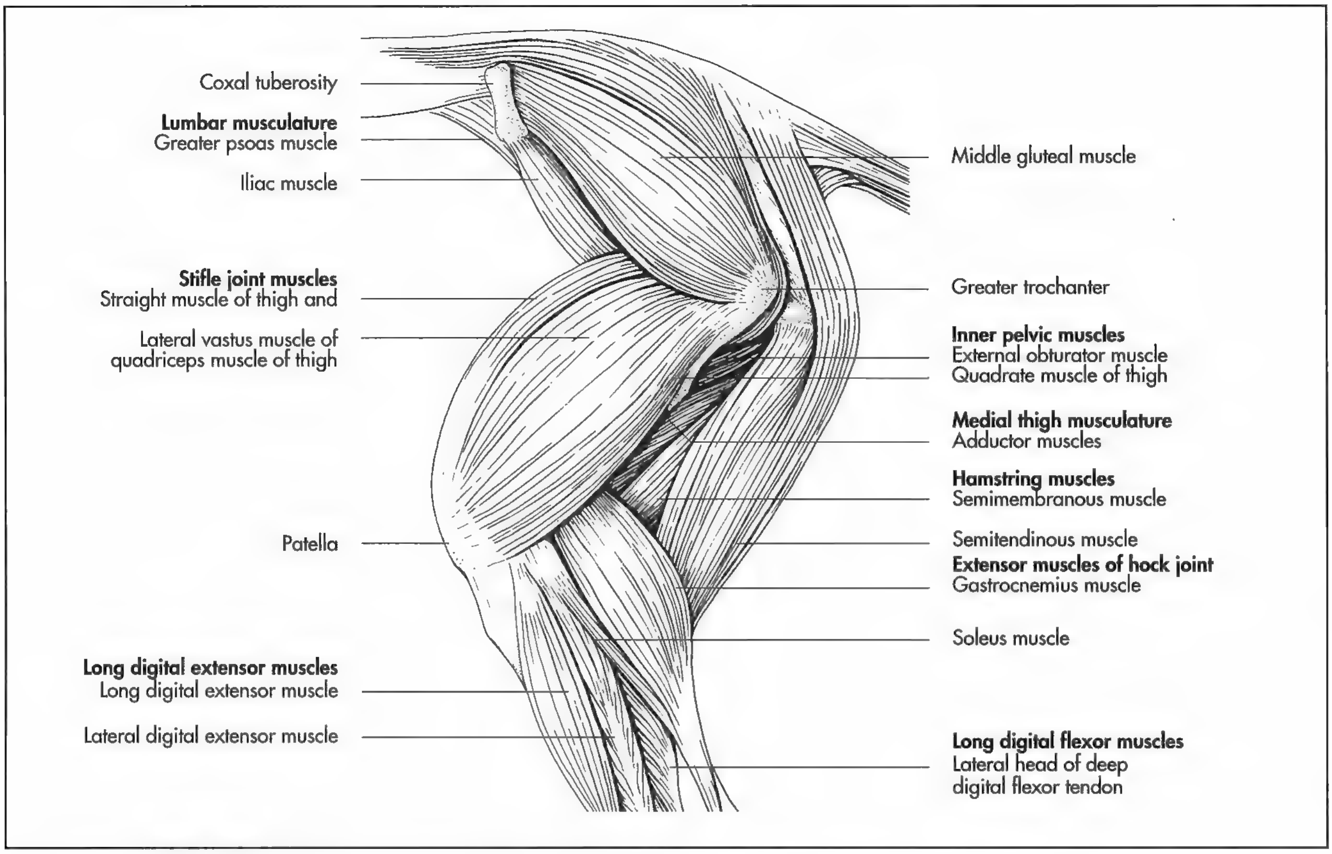

Fig. 4-80. Deep muscles of the pelvic limb of the horse (schematic, lateral aspect) (Ellenberger and Baum, 1943).

pelvic heads of the biceps muscle of the thigh and the semimembranous muscle. It extends distally along the caudal edge of the biceps muscle of the thigh and divides from it at the popliteal space to the medial side of the leg (Fig. 4-79). The semitendinous muscle detaches a strong tendon, which extends along the medial surface of the gastrocnemius muscle to the calcaneal tendon. It forms a conjoined accessory tendon of insertion together with the tarsal tendon of the biceps muscle of the thigh and the crural fascia, which inserts on the calcaneal tuberosity.

In ruminants the semitendinous is a flat muscle, which has a single head, originating from the caudoventral surface of the ischial tuberosity. It extends distally between the pelvic portions of the biceps muscle of the thigh and the semimembranous muscle to the popliteal space. The muscle inserts by a flat aponeurotic tendon which passes over the medial head of the gastrocnemius muscle and inserts on the cranial border of the proximal end of the tibia, the crural fascia and the tendon of insertion of the gracilis muscle. An additional tendon inserts on the calcaneal tuberosity.

In the horse and the pig the semitendinous muscle has two heads of origin. In addition to the pelvic head, which originates on the ventral surface of the ischial tuberosity, they possess a vertebral head originating from the sacrum, the first caudal vertebrae and the broad sacrotuberous ligament. Both heads unite and continue as a flat tendon to the medial aspect of the leg, where it partly radiates into the crural fascia and partly inserts to the cranial border of the tibia (Fig. 4-80). The remainder of the tendon joins the tarsal tendon of the biceps muscle of the thigh, with which it inserts on the calcaneal tuberosity.

The semitendinosus muscle extends the hip, stifle and tarsal joints, when the foot is placed on the ground, thus propulsing the trunk. It flexes the stifle and rotates the leg outward and moves it backward in the free non-weightbearing limb.

The **semimembranous muscle** is the most medial muscle of the hamstring group and, unlike in humans, is entirely fleshy (Fig. 4-80, 81 and 82). It arises with two heads, a vertebral and a pelvic head in the horse, and with a pelvic head only in the other domestic mammals. The pelvic head originates from the ventral aspect of the ischium. The muscle belly splits distally into two parts, one of which inserts with a short tendon to the medial condyle of the femur, the other with a longer tendon on the medial condyle of the tibia.

In carnivores the cranial belly of the semimembranous muscle runs along the caudal border of the greater adductor muscle, largely covered by the gracilis muscle. It inserts with a short tendon on the aponeurosis of the gastrocnemius muscle and it also inserts to the medial femoral condyle (Fig. 4-79 and 81).

In the horse the semimembranous muscle is a very large muscle forming, together with the semitendinous muscle, the caudal contour of the croup and thigh (Fig. 4-82). It has two heads of origin. The vertebral head takes its origin from the broad sacrotuberous ligament and the first caudal vertebrae. The stronger pelvic head arises from the ventral surface of

Tab. 4-7. Muscles of the hindlimb.

Name Innervation	Origin	Insertion	Action
Biceps muscle of the thigh Caudal gluteal nerve	Sacrum and pelvis	Patella, deep fascia of leg	Flexor of knee joint; extensor of tarsus
Pelvic head Tibial nerve		Common calcaneal tendon	Abduction of hindlimb
Abductor muscle of thigh fibular nerve	Sacrotuberal ligament	Deep fascia of leg	Abducts the limb
Semitendinous muscle Caudal gluteal nerve, tibial nerve	Vertebral and pelvic head	Cranial border of tibia, common calcaneal tendon	Flexor of the stifle joint; extensor of the hip joint
Semimembranous muscle Caudal gluteal nerve, tibial nerve	Vertebral head, pelvic head (only in the horse)	Medial condyle of femur and tibia	Extensor of the stifle joint; draws limb inwards

the ischial tuberosity. The united muscle belly passes distally, covered in part by the gracilis muscle. It inserts as a short tendon on the medial femoral condyle and the medial collateral ligament of the femorotibial joint and by means of an aponeurosis at the medial condyle of the tibia.

The semimembranous muscle extends the hip and stifle joints in the weightbearing position, thus supporting propulsion of the trunk, but adducts and retracts the limb in the non-weight bearing position.

Medial muscles of the thigh

The muscles of this group are primarily responsible for adduction of the limb. This function also embraces the prevention of unwanted abduction. They extend between the pelvic floor and the femur on the medial side of the thigh. This group comprises:

- Sartorius muscle (m. sartorius),
- Gracilis muscle (m. gracilis),
- Pectineal muscle (m. pectineus) and
- Adductor muscles (mm. adductores).

The **sartorius muscle** is a narrow strap-like muscle, which lies superficially on the craniomedial contour of the thigh (Fig 4-81).

In the dog the sartorius muscle consists of two parts. The cranial part originates on the iliaç crest, passes distally in front of the tensor fascia latae muscle and turns to the medial surface of the thigh, where it unites with the femoral fascia and the fascia of the stifle. The caudal portion originates from the ventral iliac spine and passes distally, parallel and medial to the cranial belly. It blends with the aponeurosis of the gracilis muscle and ends on the cranial border of the tibia. In carnivores the sartorius muscle does not cover the femoral triangle, thus it is a favourable site for taking the pulse.

In ruminants this muscle is divided at its origin into two heads by the passage of the femoral vessels. In the horse it originates with a single head by the iliac fascia and the tendon of the smaller psoas muscle (Fig. 4-82). It passes together with the iliopsoas through the muscular lacuna, continues distally on the medial side of the femur close to the gracilis and medial vastus muscles and unites with the medial patellar ligament and the crural fascia, thereby inserting to the tuberosity of the tibia.

The sartorius muscle flexes the hip, advances and adducts the limb. It also extends the hip through its union with the crural fascia and the fascia of the stifle.

The **gracilis muscle** forms an extensive, broad muscular sheet, which covers the greater part of the caudal part of the medial surface of the thigh (Fig. 4-81). It takes an aponeurotic origin from the region along the pelvic symphysis, the tendons of insertion of the straight muscle of the abdomen and, in the horse, from the accessory ligament of the head of the femur. Tendinous fibres of this aponeurosis unite with fibres from the opposite side in the pelvic symphysis, forming a median unpaired tendinous plate (tendo symphysialis). This plate also serves as the origin for the adductor muscles.

Its insertion, also aponeurotic merges with the crural fascia through which it attaches to the tibial crest.

The gracilis muscle is a strong adductor of the limb. It can also move the whole rump sideways, when the foot is placed firmly on the ground. It assists extension of the stifle.

The **pectineal muscle** is a small fusiform muscle, which extends between the pecten of the pubis, the iliopubic eminence of the pelvic floor and the middle of the medial border of the femur (Fig. 4-82).

In the dog it is situated cranial to the greater adductor muscle. A tendinuos origin arises from the prepubic tendon and a fleshy origin from the iliopubic eminence. It passes distally between the vastus medialis and the greater adductor muscle to form a tendinous attachment on the popliteal surface of the femur.

Tab. 4-8. Medial muscles of the thigh.

Name Innervation	Origin	Insertion	Action
Sartorius muscle Femoral nerve	Coxal tuberosity; shaft of ilium or tendon of lesser psoas muscle	Deep fascia of the leg	Adducts and draws hindlimb forwards
Gracilis muscle Obturator nerve	Aponeurosis on the symphysis	Deep fascia of the leg	Adduction
Pectineal muscle Obturator and femoral nerve	Iliopubic eminence of femur	Medial border of the femur	Adduction
Adductor muscles Obturator nerve	On the ventral surface of the pelvis and on the tendon of the gracilis	Medial border of the femur	Adduction

The pectineal muscle functions as a flexor of the hip and adductor and supinator of the limb. A common surgical procedure in dogs suffering from hip dysplasia is to dissect the pectineal muscle to prevent adduction of the limb.

The **adductor muscles** arise on the ventral aspect of the pelvic floor and the aponeurosis of origin of the gracilis muscle. They insert on the medial aspect of the femur and to the fascia and ligaments of the medial aspect of the stifle. This group is divided into several individually named parts in the different domestic species.

Carnivores have a strong **greater adductor muscle** (m. adductor magnus), which originates from the entire pelvic symphysis and symphysal tendon. It runs distally, covered by the gracilis muscle close to the medial vastus muscle and inserts on the lateral supracondylar tuberosity and the popliteal fossa (Fig. 4-81). A small **short adductor muscle** (m. adductor brevis) extends between the pubic tubercle and the caudal surface of the femur. The **long adductor muscle** (m. adductor longus) is fused to the pectineal muscle in the dog, but remains a separate muscle in cats.

In the pig the **greater** and **short adductor muscles** are fused to form a strong united muscle. At their origin they are gender specific in cross section, being oval in females, and triangular in males. This is occasionally used to identify the sex of pigs in the slaughter house.

In the horse the adductor group comprises a cranial short adductor muscle and a caudal greater adductor muscle. They are situated between the pectineal and the semimembranous muscles, covered by the gracilis muscle. They insert along the whole medial aspect of the femur, extending from the lesser trochanter to the medial condylus and to the medial collateral ligament of the sifle.

Their major function is the adduction of the limb, but they also retract the limb and move the rump forward and sideways.

Inner pelvic muscles

The inner pelvic muscles form a rather heterogenous group of small muscles, which are situated close to the hip joint. They have minor function in coordinating the movements of the hindlimb. These muscles, with the exception of the articular muscle of the hip joint are also called the small pelvic association. They extend between the pelvis and the trochanteric fossa of the femur. This group comprises:

- Internal obturator muscle (m. obturatorius internus),
- External obturator muscle (m. obturatorius externus),
- Gemellus muscles (mm. gemelli),
- Quadrate muscle of the thigh (m. quadratus femoris),
- Articular muscle of the hip joint (m. articularis coxae).

The **internal obturator muscle** exists in carnivores and the horse (Fig. 4-83 and 84). In carnivores, it arises from the ischium, pubis and the ischiatic arch and covers the obturator foramen internally. It passes over the lesser sciatic notch and forms a strong tendon, which extends distally between the gemellus and the quadrate muscles of the thigh to insert on the trochanteric fossa. In the horse the internal obturator muscle originates with a small tendinous pubic head from the cranial and medial border of the obturator foramen, the pelvic symphysis and the ischium and with a larger fleshy head from the pelvic surface of the body of the ilium. The tendon emerges through the lesser sciatic notch and inserts together with the gemellus muscles in the trochanteric fossa. This muscle rotates the femur laterally and assists in extending the hip.

The **external obturator muscle** is a pyramidal muscle, which arises close to the obturator foramen from the ventral pelvic surface and terminates in the trochanteric fossa (Fig. 4-83 and 84). Ruminants and the pig have an additional intrapelvic part, which arises from the body of the ilium, the pubis and the ischium. The external obturator muscle acts as a supinator of the femur and adductor of the limb.

The **gemellus muscles** are two small muscle bundles, that extend from the ischiatic spine to the trochanteric fossa. While they remain separated in the cat, they are fused to form a single muscle, which unites partly with the internal obturator muscle in the other domestic species. It assists in rotating the limb laterally.

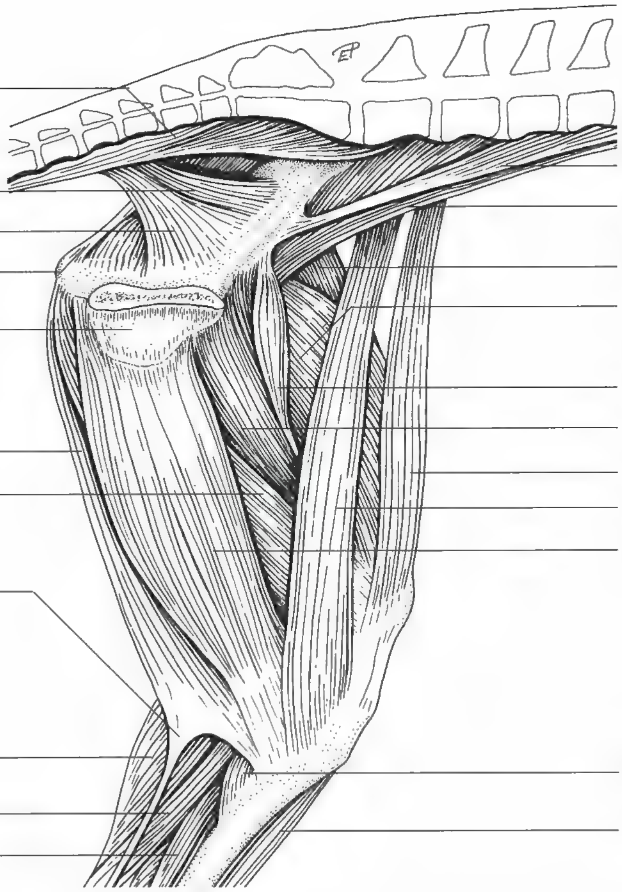

Fig. 4-81. Girdle musculature and intrinsic musculature of the pelvic limb of the dog (schematic, medial aspect) (Ellenberger and Baum, 1943).

The **quadrate muscle of the thigh** is a narrow, small muscle, which passes from the ventral aspect of the pelvis to end on the caudal side of the femoral shaft, close to the trochanteric fossa (Fig. 4-83 and 84). It assists in extending the hip and retracting the limb.

The **articular muscle of the hip joint** is a thin muscle laying directly on the craniolateral aspect of the hip joint in carnivores and the horse (Fig. 4-83). It tenses the joint capsule and thus prevents damage to the peri-articular structures of this joint.

Muscles of the stifle

Most of the hip muscles, especially the hamstring group, act on the stifle joint since they insert either on structures, which are part of the joint or which are located distal to this joint. There are only two muscles acting primarily on the stifle joint:

- Quadriceps muscle of thigh (m. quadriceps femoris),
- Popliteal muscle (m. popliteus).

The **quadriceps muscle of the thigh** forms the bulk of muscle cranial to the femur (Fig. 4-81, 82 and Table 4-10). It is covered by the tensor muscle of the fascia lata, the sartorius muscle, the fascia lata and the medial femoral fascia. It consists of four portions, which are separate at their origin, but converge to form a single tendon, that includes the **patella as a sesamoid bone** within it and ends at the tibial tuberosity as the straight ligament of the patella. The origins of the **four heads** are the same in all domestic mammals: the straight muscle of thigh originates on the shaft of the ilium, whereas the other three originate on the femur. In the dog the division in four portions is less distinct than in the other species. The quadriceps muscle can be further subdivided in:

- Lateral vastus muscle (m. vastus lateralis),
- Medial vastus muscle (m. vastus medialis),
- Intermediate vastus muscle (m. vastus intermedius),
- Straight muscle of thigh (m. rectus femoris).

The **lateral vastus muscle** lies on the craniolateral side of the femur, arising from the lateral aspect of the proximal end of the femur.

The **medial vastus muscle** resembles the preceding muscle on the craniomedial side of the femur.

The **intermediate vastus muscle** is the weakest portion of the quadriceps muscle of the thigh, situated on the cranial surface of the femur, entirely covered by the other heads of the quadriceps muscle.

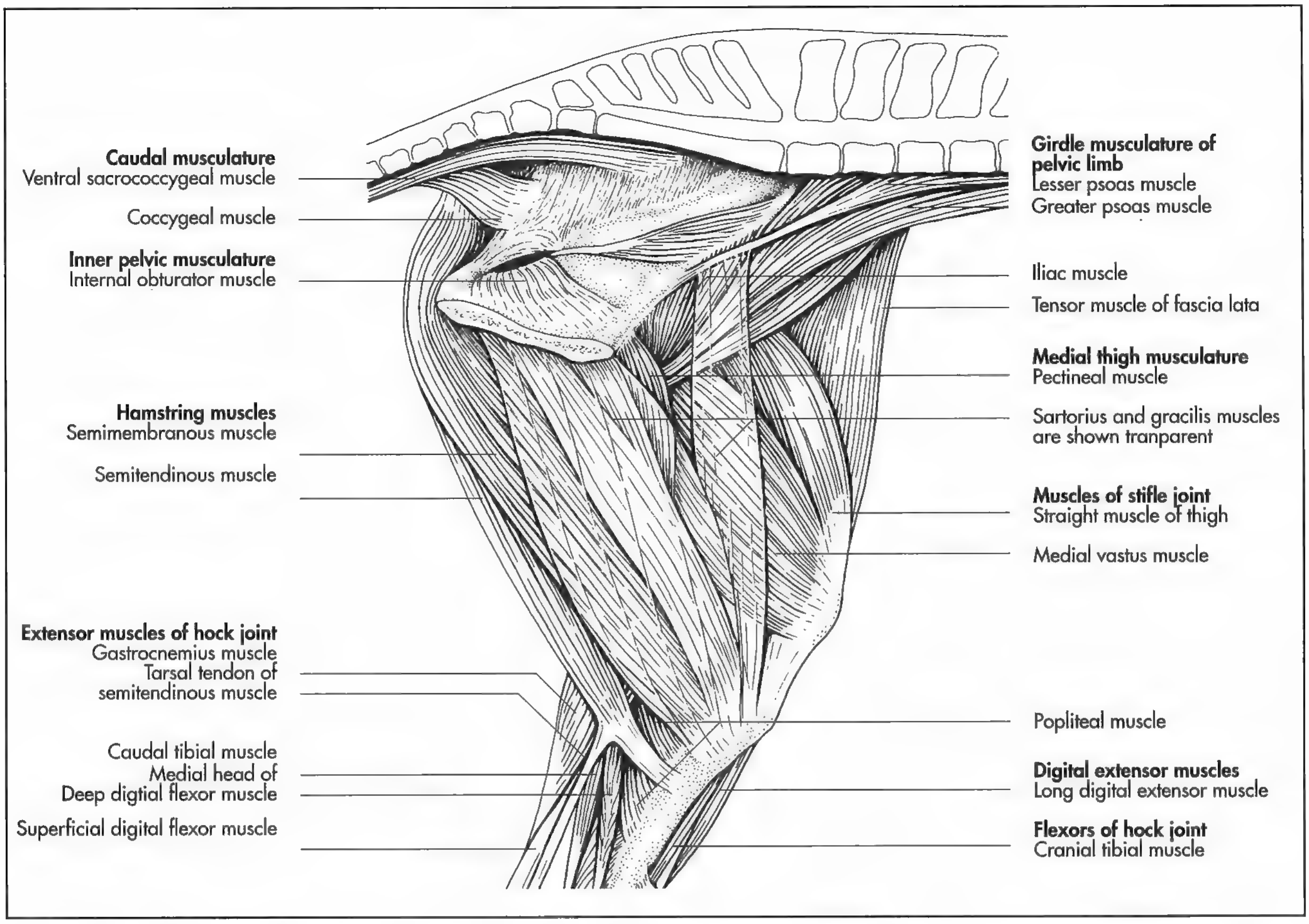

Fig. 4-82. Girdle musculature and intrinsic musculature of the pelvic limb of the horse (schematic, medial aspect) (Ellenberger and Baum, 1943).

Fig. 4-83. Inner pelvic muscles of a dog (dorsolateral aspect).

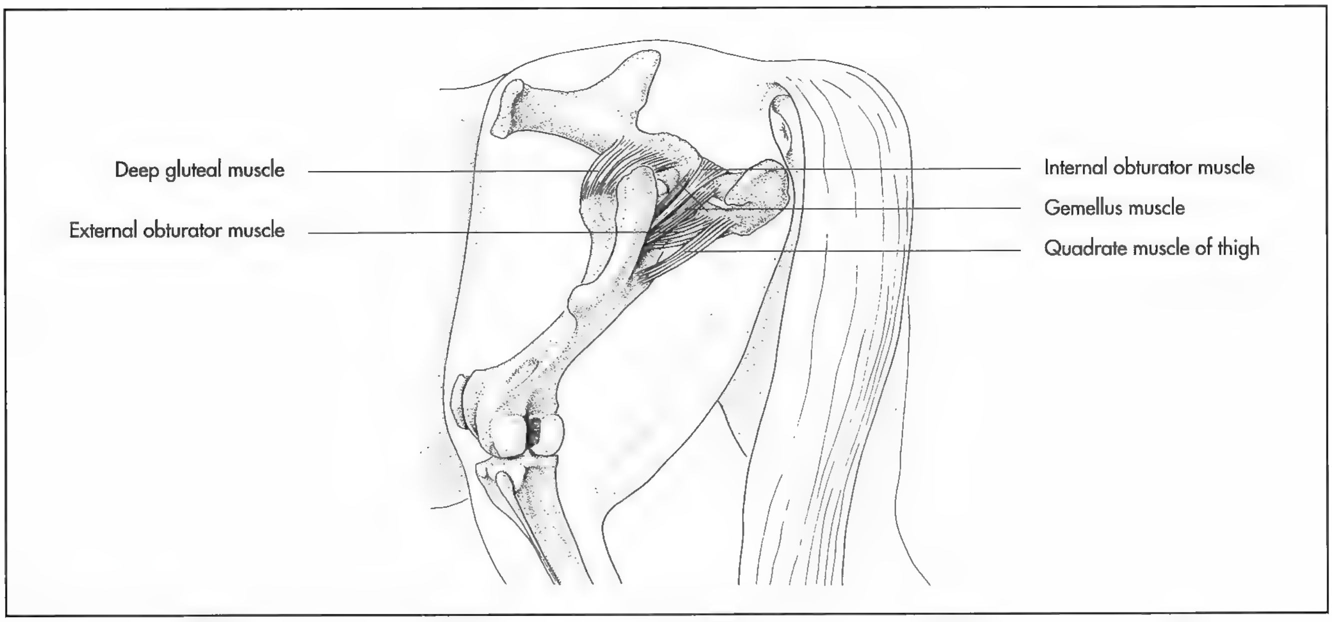

Fig. 4-84. Inner pelvic muscles of the horse (schematic, lateral aspect) (Ghetie 1967).

Tab. 4-9. Inner pelvic muscles.

Name **Innervation**	**Origin**	**Insertion**	**Action**
Internal obturator muscle Sciatic nerve	Inner surface of the obturator foramen	Trochanteric fossa	Draws hindlimb outwards
External obturator muscle Obturator nerve	Outer surface of the obturator foramen	Trochanteric fossa	Draws hindlimb outwards
Gemellus muscle Sciatic nerve	Ischium	Trochanteric fossa	Draws hindlimb outwards
Quadrate muscle of thigh Sciatic nerve	Ischium	Trochanteric fossa	Draws hindlimb outwards
Articular muscle of the hip joint Sciatic nerve	Hip joint capsule		Tensor of the joint capsule

The **straight muscle of the thigh** originates from the shaft of the ilium, just cranial to the acetabulum. It passes distally on the cranial side of the femur flanked by the medial vastus muscle on the medial side and the lateral vastus muscle on the lateral side.

In the horse the straight muscle of the thigh is the largest portion of the quadriceps muscle covering the cranial and lateral aspect of the femur. It originates with two strong tendons on the cranial rim of the acetabulum and passes distally enclosed between the lateral and medial vastus muscle, covering the intermediate muscle. A strong tendinous layer covers its surface. Its fibres converge to form the strong tendon of insertion, together with the fascia of the stifle and distal end of the muscle. The tendon of insertions is joined by the tendons of the other portions of the quadriceps muscle to attach to the tibial tuberosity as the middle patellar ligament. A **synovial bursa** is interposed between the ligament and the tibial tuberosity.

The quadriceps muscle of the thigh is the strongest extensor of the stifle joint. It propulses the rump and stabilises the stifle. The straight muscle of the thigh assists in flexing the hip.

The small **popliteal muscle** lies directly over the caudal aspect of the stifle joint (Fig. 4-85). It has a tendinous origin arising from the lateral condyle of the femur. It passes underneath the lateral collateral ligament and extends between the this and the lateral meniscus of the stifle. It inserts as a broad tendon on the caudal and medial surface of the proximal end of the tibia. Its tendon of origin contains a sesamoid bone in carnivores. It is a flat triangular muscle in the horse, covered by the gastrocnemius muscle and the superficial flexor tendon. Its tendon of origin is invested by a reflection of the synovial membrane of

Tab. 4-10. Muscles of the stifle.

Name Innervation	Origin	Insertion	Action
Quadriceps muscle of the thigh Femoral nerve			
Straight muscle of the thigh	Shaft of ilium	Patella, tibial tuberosity	Extensor of the stifle joint; flexor of the hip joint
Lateral vastus muscle	Lateral surface of femur	Patella, tibial tuberosity	Extensor of the stifle joint
Medial vastus muscle	Medial surface of femur	Patella, tibial tuberosity	Extensor of the stifle joint
Intermediate vastus muscle	Cranial surface of femur	Patella, tibial tuberosity	Extensor of the stifle joint
Popliteal muscle Tibial nerve	Lateral condyle of femur	Medial border of tibia	Flexor of the stifle joint; draws limb inwards

the femorotibial joint capsule, which functions as a tendon sheath. It acts as a flexor of the stifle and pronator of the leg.

Muscles of the crus

The muscles of the crus comprise **extensors and flexors of the tarsus and extensor and flexors of the digit**. They are grouped in two masses according to the location of their bellies, one on the craniolateral aspect of the tibia, the other one on the caudal aspect of the tibia, whereas the medial surface is left free of muscular bellies (planum cutaneum). Unlike the carpal joints of the forelimb, the tarsal joints are set at an angle opposite to that of the digital joints. The flexor side of the tarsal joints is dorsally, whereas the flexor side of the digital joints is plantar. The muscles on the craniolateral side of the crus are flexors of the tarsus and extensors of the digits, whereas the muscles on the caudal side acts as flexors of the digits and extensor of the tarsus.

Craniolateral muscles of the crus

The craniolateral crural muscles have long, extended fleshy bellies and arise either from the distal end of the femur or from the proximal end of the tibia or fibula (Fig. 4-86). Their tendons of insertion are multiarticular and divide into a branch for each functional digit, that inserts either to the metatarsus or the phalanges. They are innervated by the peroneal nerve (n. peroneus).

This group can be divided into:

Flexors of the tarsus:
- Cranial tibial muscle (m. tibialis cranialis),
- Long peroneal (fibular) muscle (m. peronaeus (fibularis) longus),
- Short peroneal (fibular) muscle (m. peronaeus (fibularis) brevis),
- Third peroneal (fibular) muscle (m. peronaeus (fibularis) tertius).

Extensors of the digits:
- Long digital extensor muscle (m. extensor digitorum longus),
- Lateral digital extensor muscle (m. extensor digitorum lateralis),
- Long extensor muscle of first digit (m. extensor hallucis longus).

The **cranial tibial muscle** is the most medial muscle on the cranial aspect of the tibia and is partly covered by the third peroneal muscle and the long digital extensor muscle (Fig. 4-86 and Tab. 4-11). It originates from the lateral condyle of the tibia and the proximal end of the fibula and inserts on the medial aspect of the tarsus or proximal metatarsus.

In carnivores the cranial tibial muscle is a superficial, strong muscle, which is covered proximally by the skin and the crural fascia only. It becomes a flat tendon at the distal third of the tibia. This tendon extends obliquely over the flexor side of the tarsus, passes under the extensor retinaculum of the crus and inserts on the rudiment of the first metatarsal bone, the first tarsal bone and to the proximal end of the second metatarsal bone. The tendon of insertion of the cranial tibial muscle and the long extensor muscle of first digit are surrounded by a synovial sheath at the level of the tarsus (Fig. 4-89 to 92).

In the horse the cranial tibial muscle is united by tendinous and fleshy fibres with the third peroneal muscle proximal to the tarsus. At the level of the tarsus the cranial tibial muscle continues as a strong tendon, which emerges between the middle and medial branch of the third peroneal muscle and bifurcates into a medial and lateral branch. The lateral branch inserts to the proximal end of the metatarsus. The medial, stronger branch passes mediodistally over the medial branch of the third peroneal muscle and inserts at the fused first and second tarsal bone, where a synovial bursa is interposed. This branch is also called cunean tendon and its resection is recommended by some clinicians for the relief of spavin.

The **long peroneal (fibular) muscle** is a weak muscle on the lateral surface of the crus arising from the proximal end of the fibula, the lateral condyles of the tibia and the lateral

Fig. 4-85. Left stifle joint and popliteus of a dog (caudal aspect) (courtesy of Dr. R. Macher, Vienna).

collateral ligament of the stifle joint (Fig. 4-86). Its long tendon of insertion passes over the lateral aspect of the flexor side of the tarsus and runs over a groove between the fourth tarsal and fourth metatarsal bone to the plantar surface of the metatarsus, where it inserts on the proximal parts of the medial metatarsal bone. It is not present in the horse.

In the dog the long peroneal muscle is the strongest of the peroneal group of muscles (Fig. 4-92 to 95). Its thin tendon of insertion crosses the tendons of insertion of the lateral digital extensor and the short peroneal muscle at the lateral side of the tarsus superficially. It passes in a sharp curve medially to the plantar surface of the metatarsus to insert to the proximal end of the medial metatarsal bone.

In ruminants the long peroneal muscle tapers to a long flat tendon at the proximal half of the tibia and runs distally between the lateral and common digital extensor tendon. It crosses over the lateral digital extensor tendon and under the lateral collateral ligament of the tarsus to the medial surface of the tarsus, where it inserts on the first tarsal bone.

The **short peroneal (fibular) muscle** is only present in carnivores. It is the deepest muscle of the peroneal group of muscles. It originates, covered by the long peroneal muscle, on the distal half of the fibula and tibia. Its tendon passes distally deep to the lateral collateral ligament of the tarsus and the tendon of the long peroneal muscle to insert on the proximal end of the fifth metatarsal bone.

The **third peroneal (fibular) muscle** is an exclusively tendinous muscle in the horse and a strong fleshy muscle in ruminants, where it is fused to the long digital extensor muscle at its origin (Fig. 4-86). It is not present in carnivores. It originates from the extensor fossa of the lateral femoral condyle and inserts on the distal tarsus or the proximal metatarsus. The third peroneal muscle is important in the horse, where it constitutes an essential component of the **reciprocal apparatus** (see chapter 5). The tendon links the action of the stifle and hock, thus it is not possible to flex or extend one of these joints without the other. It originates by the means of a strong tendon with the long digital extensor tendon from the extensor fossa of the lateral femoral condyle, where a pouch of the femorotibial joint capsule passes beneath the tendon. It is bound, together with the long digital extensor tendon, by the extensor retinaculum at the dorsal aspect of the tarsus. The tendon passes distally under the long digital extensor tendon in the extensor groove of the tibia, partly fused to the cranial tibial muscle and divides into three branches. The lateral branch inserts on the calcaneus and the fourth tarsal bone. The broad middle branch passes parallel to the lateral branch of the cranial tibial muscle and inserts on the third tarsal bone, the central tarsal bone and the cannon bone. The medial branch fans out to insert also to the third tarsal bone, the central tarsal bone and the third metatarsal bone.

The **long digital extensor muscle** arises together with the third peroneal muscle from the extensor fossa of the lateral femoral condyle and inserts on the flexor side of the tarsus (Fig. 4-86 and 87). The tendon of insertion divides into a branch for each functional digit further distally to end on the extensor process of the distal phalanx.

In carnivores the muscle belly of the long digital extensor muscle usually lies superficially between the cranial tibial and the long peroneal muscle. An outpouching of the femorotibial joint capsule extends between the tibia and the long digital extensor tendon at its origin. It divides into four tendons of insertion at the level of the tarsus, where they are bound by two transverse fibrous bands, the proximal and distal extensor retinaculum and enclosed in a common synovial sheath. The tendons of insertion extend distally along the

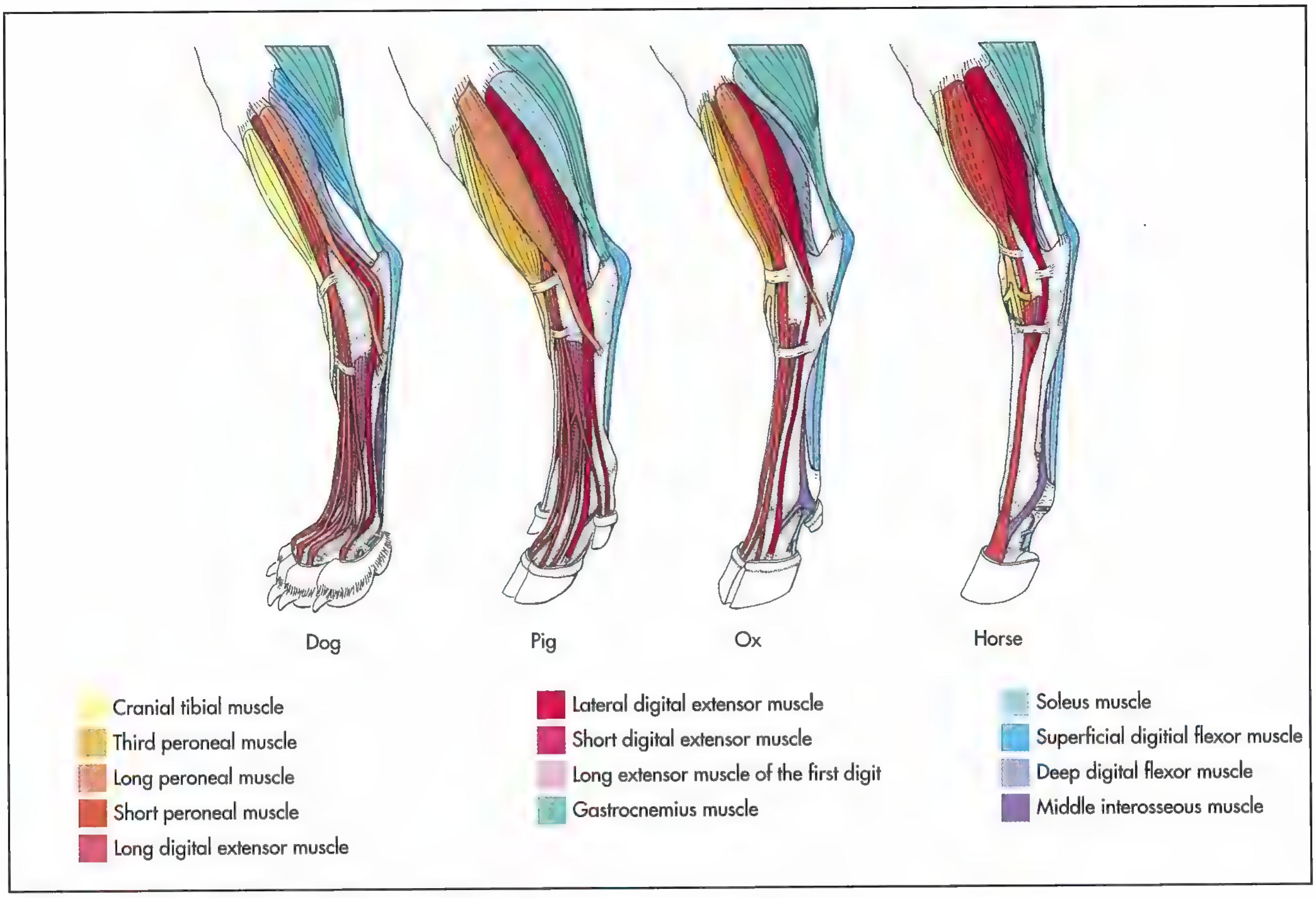

Fig. 4-86. Muscles of the crus (schematic, lateral aspect) (Ellenberger and Baum, 1943).

dorsal surfaces of the metatarsal bones and digits. They attach to the distal phalanx of the second to fifth digit, after they have received a branch from the interosseous muscle.

In ruminants the long digital extensor muscle has a common origin with the cranial tibial muscle, which covers it. It divides into two bellies, which continue distally as the lateral and medial tendons of insertion. The medial tendon inserts to the middle phalanx of the medial digit after fusing with a branch from the interosseous muscle. The lateral tendon bifurcates at the level of the fetlock joint to insert on the distal phalanx of the two main digits. Theses tendons are enclosed by synovial sheaths.

In the horse the long digital extensor muscle shares a common tendon of origin with the third peroneal muscle under which an outpouching of the femorotibial joint extends 12 to 15 cm distally (Fig. 4-87 and Fig. 4-96 to 4-99). The long tendon of insertion is held in place at the level of the tarsus by proximal, middle and distal transverse bands and is surrounded by a synovial sheath from the midtarsus to 3–4 cm beyond the tarsus distally. It is joined by the tendon of the lateral digital extensor muscle in the middle of the third metatarsal bone and receives two branches from the interosseous muscle before it inserts on the extensor process of the distal phalanx.

The long digital extensor extends the digits and assists in flexing the tarsus.

The **lateral digital extensor muscle** originates from the proximal part of the fibula and the lateral collateral ligament of the stifle. It lies deep to the long peroneal muscle in carnivores, but superficially in the other domestic mammals.

In carnivores its small belly continues distally as a thin tendon, which crosses over the lateral malleolus, passes deep to the lateral collateral ligament over the lateral surface of the tarsus and passes distally on the dorsolateral side of the metatarsus and digits to join the tendon of the long digital extensor muscle, with which it inserts to the distal phalanx of the fifth digit.

In the pig the tendon splits into two branches, one for each principal digit.

In ruminants the lateral digital extensor muscle takes its origin from the lateral collateral ligament of the stifle and from the lateral condyle of the tibia. Its strong tendon passes under the long peroneal muscle to the lateral side of the tarsus and extends on the dorsolateral aspect of the metatarsus and inserts on the middle phalanx of the fourth digit after receiving a branch from the interosseous muscle.

In the horse the lateral digital extensor muscle lies superficially between the long digital extensor muscle and the long flexor muscle of the first digit. Its round tendon passes over the lateral malleolus to the lateral aspect of the hock, where it is held in place by the proximal and distal retinacula and pro-

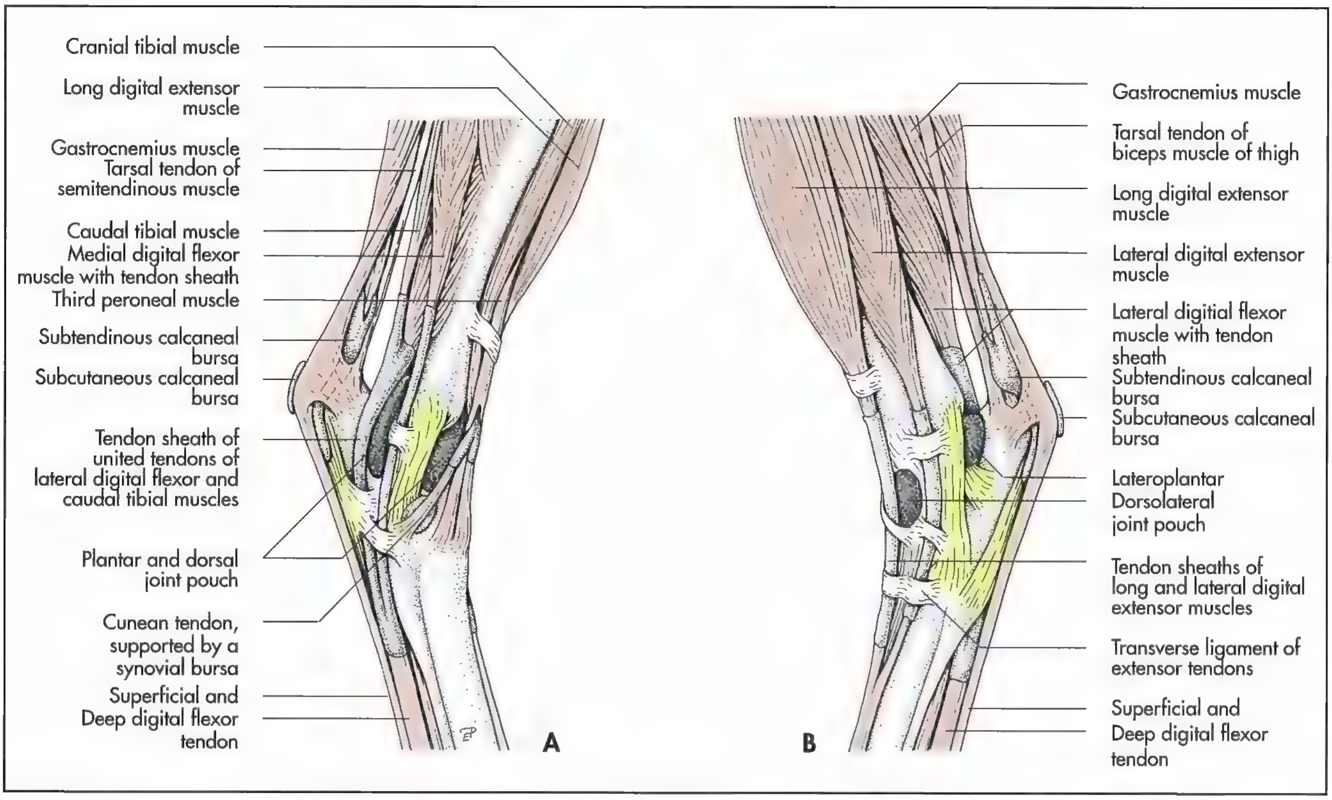

Fig. 4-87. Tendon sheaths and synovial bursae of the left tarsus of the horse (schematic, medial aspect **A**, lateral aspect **B**) (Ellenberger and Baum, 1943).

tected by a synovial sheath. It inserts by joining the tendon of the long digital extensor muscle.

The lateral digital extensor muscle extends the digits and assists in flexing the hock.

The **long extensor muscle of the first digit** forms a separate delicate muscle in carnivores, sheep and pigs, while in the goat, cattle and the horse it is fused to the cranial tibial muscle. In carnivores it lies directly over the tibia, covered by the long peroneal muscle. It originates from the proximal part of the fibula and the interosseous membrane. Its thin tendon, which occassionally broadens into an aponeurosis, passes over the dorsal surface of the tarsus and the second metatarsal bone to the metatarsophalangeal joint of the second and if present of the first digit. It extends the second and also the first digit, if it attaches to it and assists in flexing the tarsus.

Caudal muscles of the crus

The extensors of the tarsus and flexors of the digits lie on the caudal side of the crus. They arise from the distal ends of the femur and/or from the proximal end of the tibia and fibula. The extensors of the tarsus insert on the calcaneus, the flexors of the digits continue to the middle and distal phalanges. All muscles of this group are innervated by the tibial nerve (Tab. 4-12). This group comprises:

Extensors of the tarsus:
- Gastrocnemius muscle (m. gastrocnemius),
  - Soleus muscle (m. soleus).

Flexors of the digits:
- Superficial digital flexor muscle (m. flexor digitorum superficialis)
- Deep digital flexor muscle (m. flexor digitorum profundus), which can be further subdivided into three heads:
  - Caudal tibial muscle (m. tibialis caudalis),
  - Lateral digital flexor (m. flexor digitorum lateralis, formerly called m. flexor hallucis longus),
  - Medial digital flexor (m. flexor digitorum medialis, formerly called m. flexor digitorum longus).

The **gastrocnemius muscle** is a strong muscle, which originates with two heads from the caudolateral and caudomedial aspect of the femur proximal to the condyles. They terminate in a **common tendon** (tendo gastrocnemius), which constitutes the principal part of the **common calcaneal tendon** (tendo calcaneus communis) and inserts on the calcaneus (Fig. 4-86).

In carnivores the **medial head** arises from the medial lip of the distal extremity of the femur and the **lateral head** from the lateral lip (Fig. 4-92 to 95). In the cat the muscle originates from the patella and the fascia lata. Each head encloses a prominent sesamoid bone, the lateral and medial sesamoid bones of the gastrocnemius muscle, also called fabellae. The two heads run distally in close relationship to the superficial digital flexor tendon and are united by a strong tendinous plate before they combine further distally to form a common tendon. The tendon of insertion passes under the superficial flexor tendon and inserts beneath the latter to the calcaneus.

Fig. 4-88. Acrylic cast of the synovial structures of the tarsus of a horse (medial aspect).

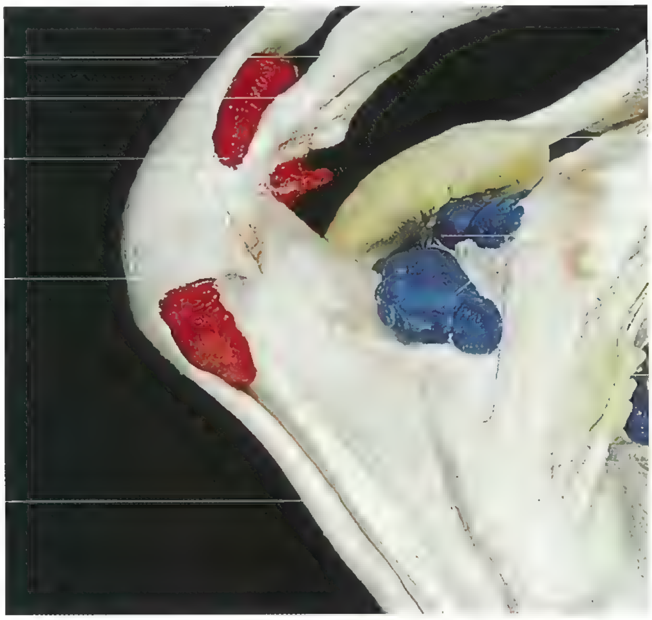

Fig. 4-89. Acrylic cast of the synovial structures of the tarsus of a horse (lateral aspect).

A **synovial bursa** is interposed between the tendon of insertion and the calcaneus.

In the horse the gastrocnemius muscle arises with two strong fusiform heads, which contain multiple tendinous intersections (Fig. 4-96 to 4-99). They originate, covered by the muscles of the hamstring group, from the lateral and medial side of the supracondylar fossa of the femur. The two heads almost completely enclose the superficial flexor tendon and combine distally to continue as a single strong tendon to the calcaneus, where it inserts deep to the superficial flexor tendon.

The gastrocnemius muscle extends the tarsus and assists in flexing the stifle.

The **soleus muscle** is a weak muscular band, which is not present in the dog. In ruminants and horses it originates from the proximal rudiment of the fibula, fans out in a distocaudal direction and fuses with the lateral head of the gastrocnemius to become part of the gastrocnemius tendon (Fig. 4-86 and 96).

The **superficial digital flexor muscle** takes its origin from the supracondylar fossa on the caudal aspect of the femur. It first passes deeply, enclosed between the two heads of

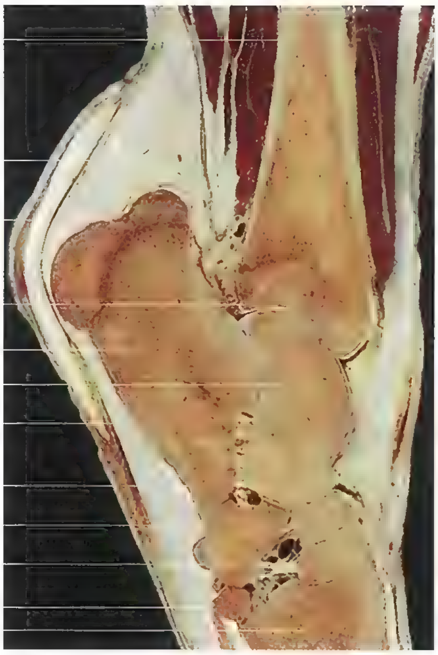

Fig. 4-90. Lateral paramedian section of the tarsus of a horse (courtesy of Dr. Margit Teufel, Vienna).

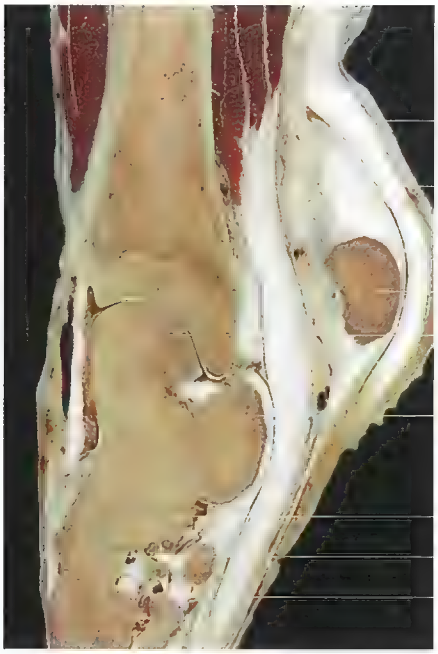

Fig. 4-91. Medial paramedian section of the tarsus of a horse (courtesy of Dr. Margit Teufel, Vienna).

the gastrocnemius (Fig. 4-86). At the middle of the crus it winds medially to a more superficial position on the caudal surface. At the calcaneus it broadens to form a **cap,** which is held in place by medial and lateral retinaculae. A **synovial bursa** lies between the cap and the calcaneal tuberosity (bursa subtendinea calcanei). The superficial digital flexor tendon continues distally and divides into a branch for each functional digit at the distal tarsus which inserts on the middle phalanx. At the level of the meatarsophalangeal joints, the tendons of insertion form cylinders **(manica flexoria)** as on the thoracic limb, which surround the corresponding branches of the deep digital flexor tendon. The distal part of the deep digital flexor tendon basically corresponds to the forelimb.

In carnivores the deep digital flexor muscle arises, firmly united with the lateral head of the gastrocnemius muscle, on the lateral supracondylar tuberosity of the femur. At the middle of the tibia the tendinous fibres of the fleshy muscle belly converge to form a strong tendon, which passes medially around the gastrocnemius tendon to the caudal surface of the point of the hock, where it forms a broad cap. The tendon continues over the plantar aspect of the hock and divides twice at the distal row of the tarsal bones. The resulting four branches extend distally over the second to fifth metatarsal bones and insert to the middle phalanx of these digits.

In ruminants and pigs the terminal tendons insert to the middle phalanx of the principal digits.

In the horse the superficial digital flexor muscle is almost entirely tendinous and constitutes a major component (tendo plantaris) of the common cunean tendon (tendo calcaneus communis), the caudal part of the **reciprocal apparatus.** The superficial digital flexor muscle arises from the supracondylar fossa of the femur, where it is intimately attached to the lateral head of the gastrocnemius muscle. A the distal third of the tibia it passes around the medial surface of the gastrocnemius tendon to occupy a position caudal to it. It widens out at the point of the hock to form a cap over the calcaneal tuber, to which it detches a band on either side. A large synovial bursa (bursa subtendinea calcanei) is interposed between the calcaneal tuber and the superficial digital flexor tendon, which can be injected from the medial side, about three cm dorsal to the calcaneus. Further distally it is arranged as in the thoracic limb and attaches to the middle phalanx.

The superficial digital flexor muscle extends the digits it inserts to, but also assists in extending the hock and flexing the stifle. In the horse it is a major component of the caudal part of the reciprocal apparatus.

The **deep digital flexor muscle** (Fig. 4-86 and 87, 4-92 to 95 and 4-96 to 99) consists of **three separate heads:**

- Caudal tibial muscle (m. tibialis caudalis),
- Lateral digital flexor muscle (m. flexor digitorum lateralis),
- Medial digital flexor muscle (m. flexor digitorum medialis).

The three heads lie on the caudal surface of the tibia and fibula from which they take origin. They unite to form a strong tendon, the **deep digital flexor tendon,** either at the middle of the crus or distal to the tarsus in different species. The common tendon continues distally on the plantar aspect of the metatarsus and inserts with a branch for each functional digit on the flexor surface of the distal phalanges, thus resulting in four tendons of insertion in carnivores and pigs, two in ruminants and one in the horse. The individual branches are surrounded by synovial sheaths at the level of the tarsus. In carnivores, the lat-

Tab. 4-11. Flexors of the tarsus and extensors of the digits.

Name Innervation	Origin	Insertion	Action
Cranial tibial muscle Fibular nerve	Lateral condyle of tibia	Tarsal and metatarsal bones	Flexor of tarsus
Long peroneal muscle Fibular nerve	Fibula and lateral condyle of tibia	Tarsal or metatarsal bones	Flexor of tarsus, draws limb inwards
Short peroneal muscle Fibular nerve	Fibula	Metatarsal bone	Flexor of tarsus
Third peroneal muscle Fibular nerve	Extensor fossa of femur	Tarsal bones metatarsal bones	Flexor of tarsus, Extensor of stifle joint
Long digital extensor muscle Fibular nerve	Extensor fossa of femur	Extensor process of distal phalanx	Extensor of the digits; extensor of stifle joint
Lateral digital extensor muscle Fibular nerve	Fibula and lateral condyle of tibia	Middle phalanx of 5th or 4th digit; distal phalanx in the horse	Extensor of the digits
Long extensor muscle of the first digit Fibular nerve	Fibula	2nd digit	Extensor of the 2nd digit

eral digital flexor muscle occupies the caudolateral side of the crus. Its strong tendon fuses with the weaker tendon of the medial digital flexor muscle on the plantar surface of the tarsus to form the deep flexor tendon. It divides into four branches which insert on the second to fifth digit at the middle of the metatarsus. These tendons of insertion are similar to the branches of the deep digital flexor tendon of the thoracic limb.

The medial digital flexor muscle lies medial to the lateral digital flexor muscle and originates on the head of the fibula and the popliteal line of the tibia. Its fine tendon passes distally along the tendon of the caudal tibial muscle to the tarsus, where it unites with tendon of the lateral digital flexor muscle. The caudal tibial muscle is a weak muscle, which lies directly on the caudomedial surface of the tibia. Its delicate tendon radiates into the medial ligamentous mass of the tarsus and does not participate in the formation of the deep digital flexor tendon as it does in the other domestic species.

In ungulates the lateral digital flexor muscle originates from the lateral tibial condyle and the caudal surface of the tibia, covered by the caudal tibial muscle proximally. Its strong tendon unites with the tendon of the caudal tibial muscle at the distal third of the crus and then passes over the sustentaculum of the talus. The common tendon is joined by the tendon of the medial digital flexor muscle at the proximal part of the metatarsus.

The medial digital flexor muscle runs along the medial surface of the lateral digital flexor muscle and passes, as a round tendon, over the medial aspect of the tarsus to the metatarsus, where it joins the common deep flexor tendon. The deep digital flexor tendon ends as the corresponding tendon of the forelimb. In the horse the deep digital flexor tendon runs over the distal sesamoid bone, where its passage is faciliated by the **navicular bursa** (bursa podotrochlearis), to insert on the distal phalanx.

The deep digital flexor flexes the digits and assists in extending the tarsus.

Short digital muscles

The short digital muscles are similar to the like-named muscle in the thoracic limb. In general these muscles are well-developed in carnivores, but rudimentary or missing in the other domestic mammals, with the exception of the interosseous muscles.

The short digital muscles comprise:

- Short digital extensor muscle (m. extensor digitorum brevis),
- Short digital flexor muscle (m. flexor digitorum brevis),
- Interflexor muscles (mm. interflexorii),
- Interosseous muscles (mm. interossei),
- Lumbrical muscles (mm. lumbricales) and
- Plantar quadrate muscle (m. quadratus plantae).

The **short digital extensor muscle** lies on the dorsal side of the metatarsal bones and lateral to the long digital extensor tendon. It is a weak muscular band in ruminants and horses, stronger in pigs and carnivores. In carnivores it splits into several branches, which insert together with the corresponding tendons of the common extensor tendon after they have combined with branches from the interosseous muscles.

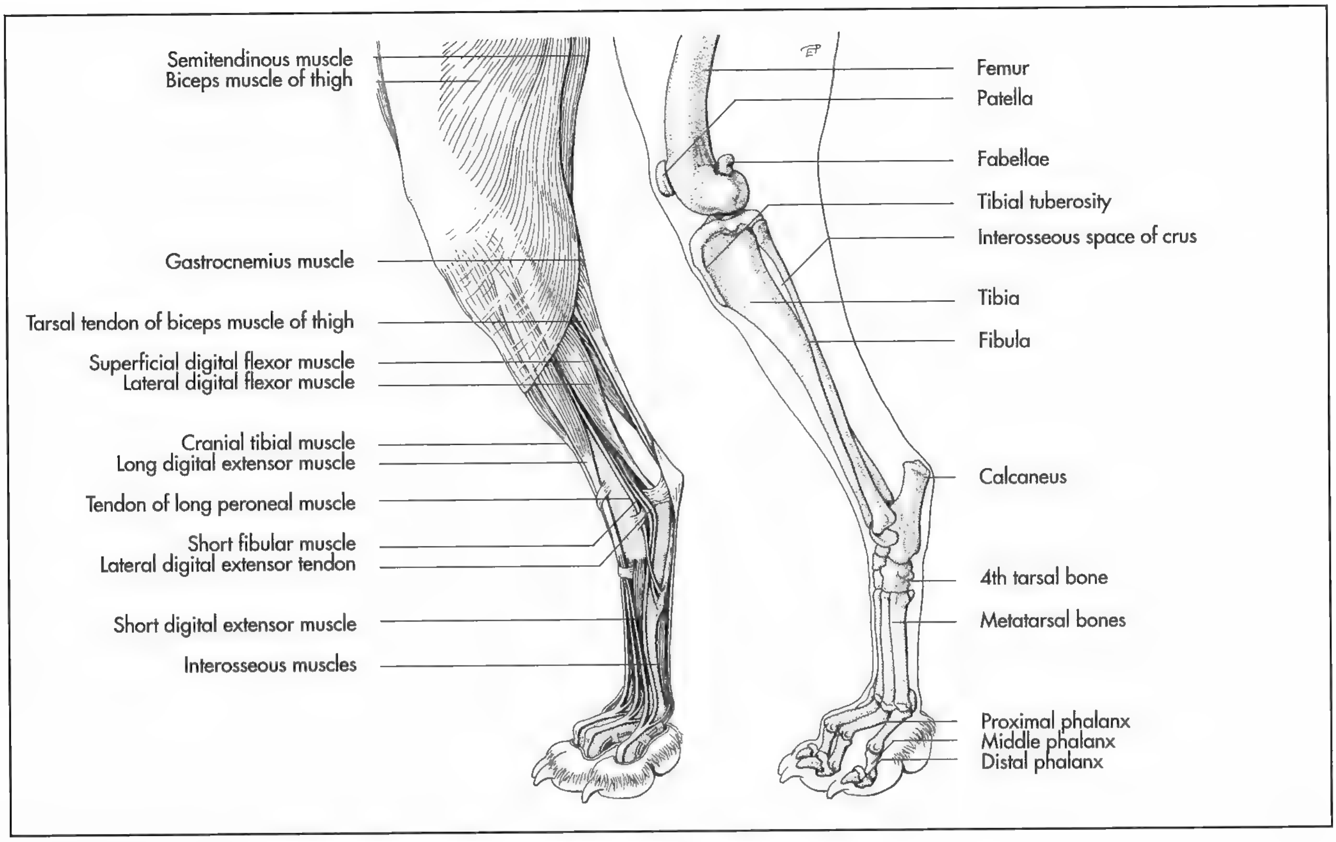

Fig. 4-92. Muscles and skeleton of the hindlimb of the dog (schematic, lateral aspect).

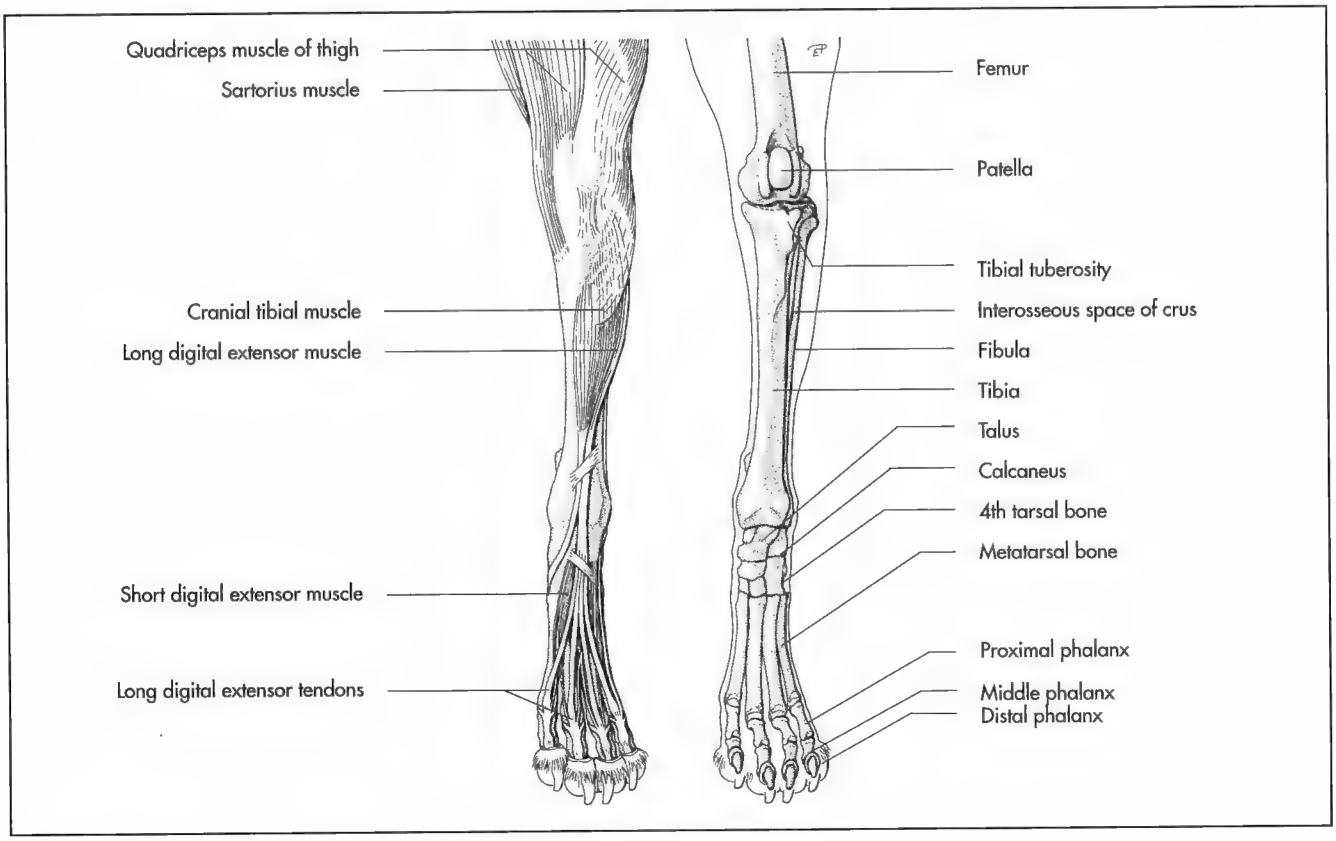

Fig. 4-93. Muscles and skeleton of the hindlimb of the dog (schematic, cranial aspect).

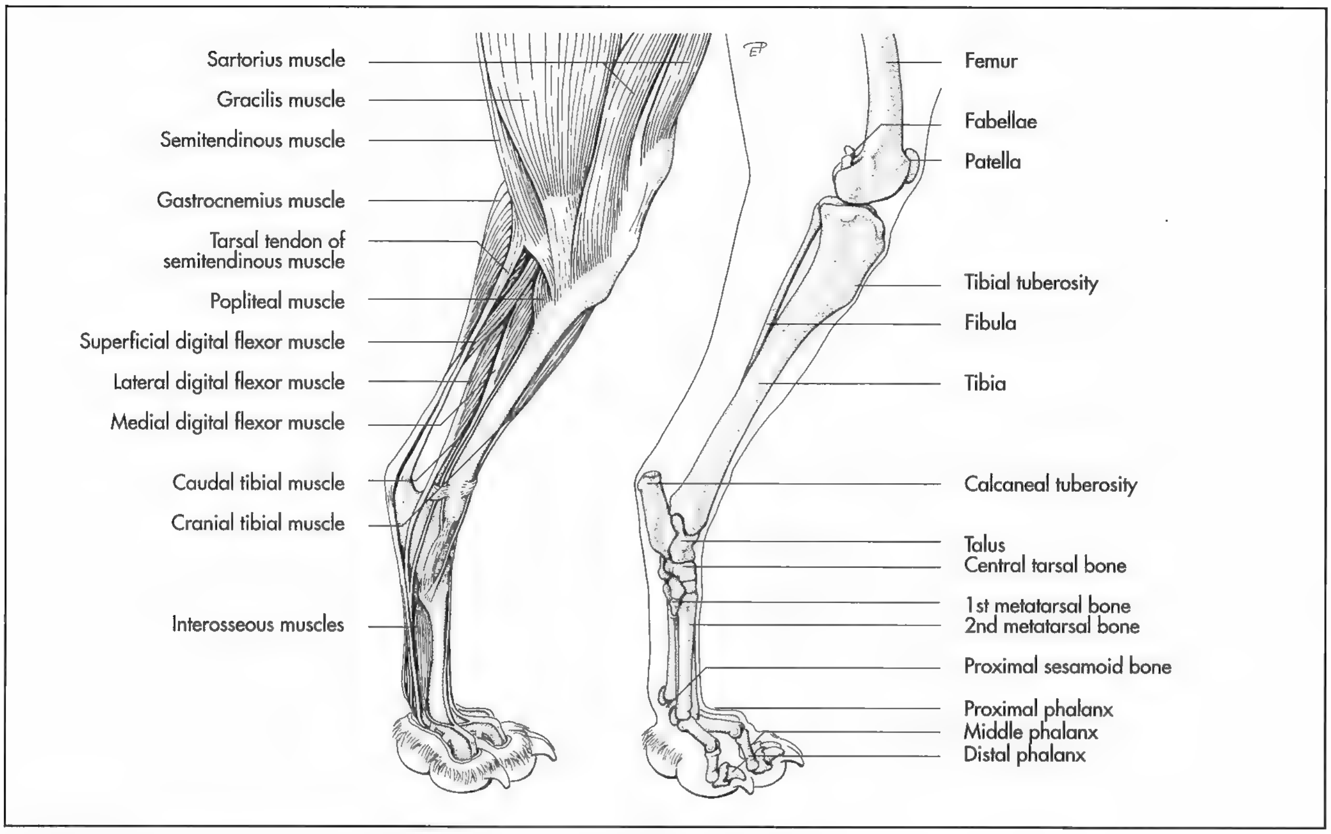

Fig. 4-94. Muscles and skeleton of the hindlimb of the dog (schematic, medial aspect).

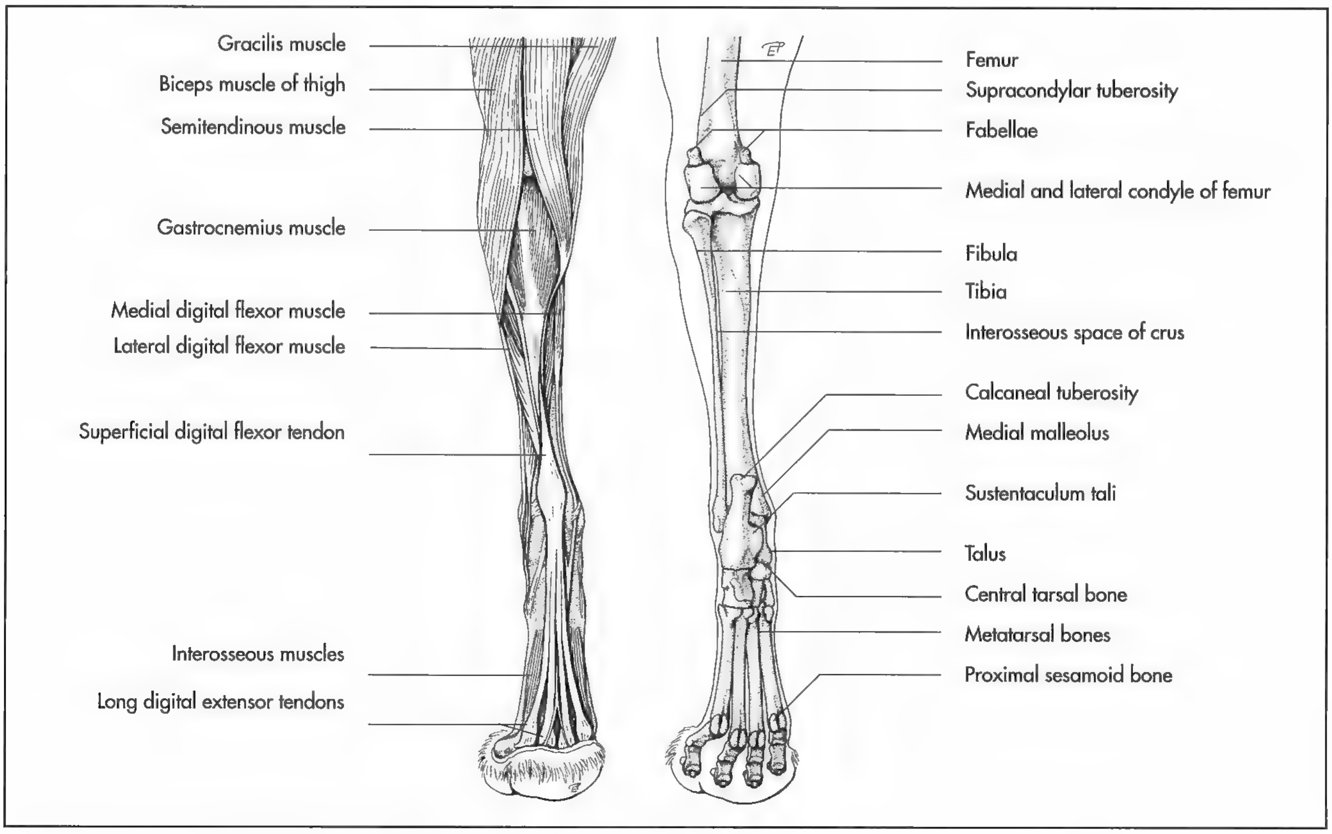

Fig. 4-95. Muscles and skeleton of the hindlimb of the dog (schematic, caudal aspect).

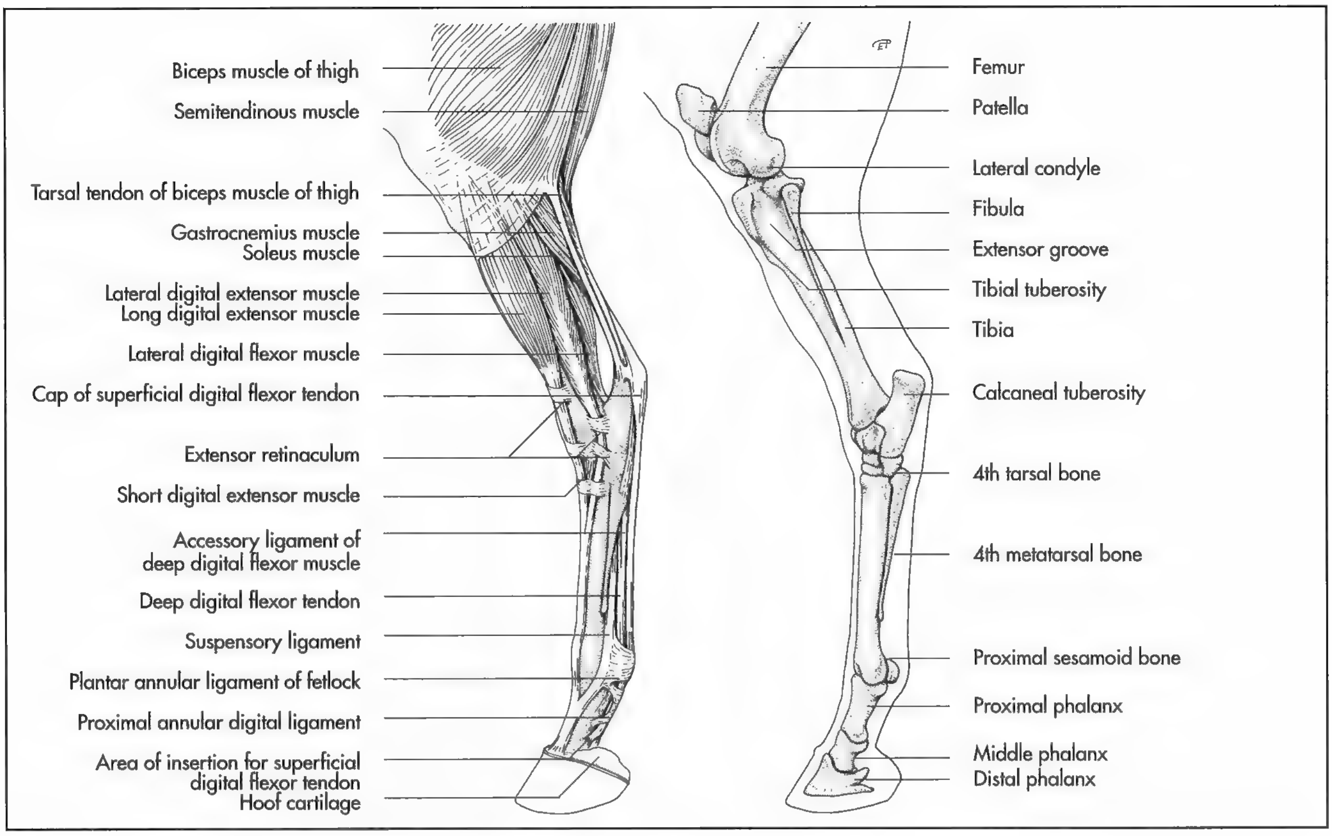

Fig. 4-96. Muscles and skeleton of the hindlimb of the horse (schematic, lateral aspect).

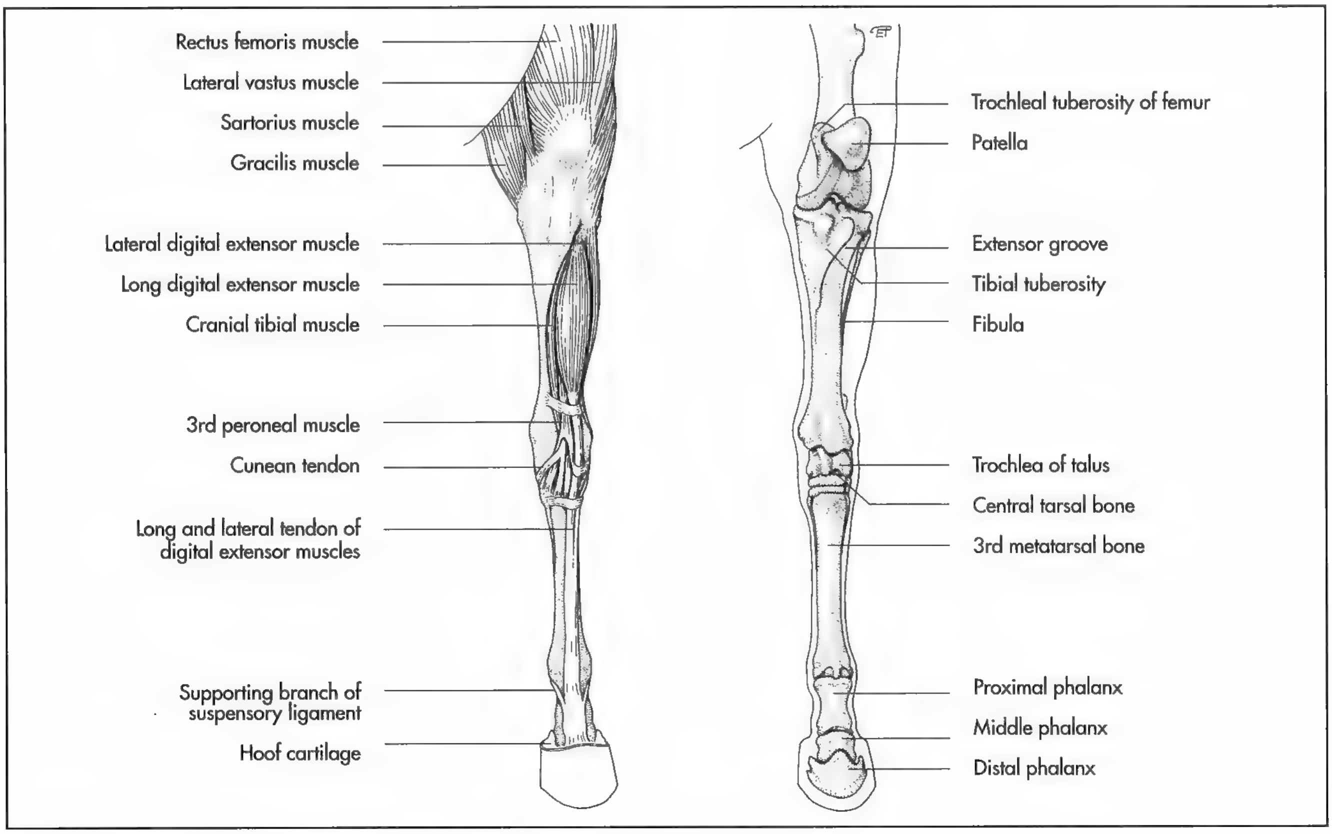

Fig. 4-97. Muscles and skeleton of the hindlimb of the horse (schematic, cranial aspect).

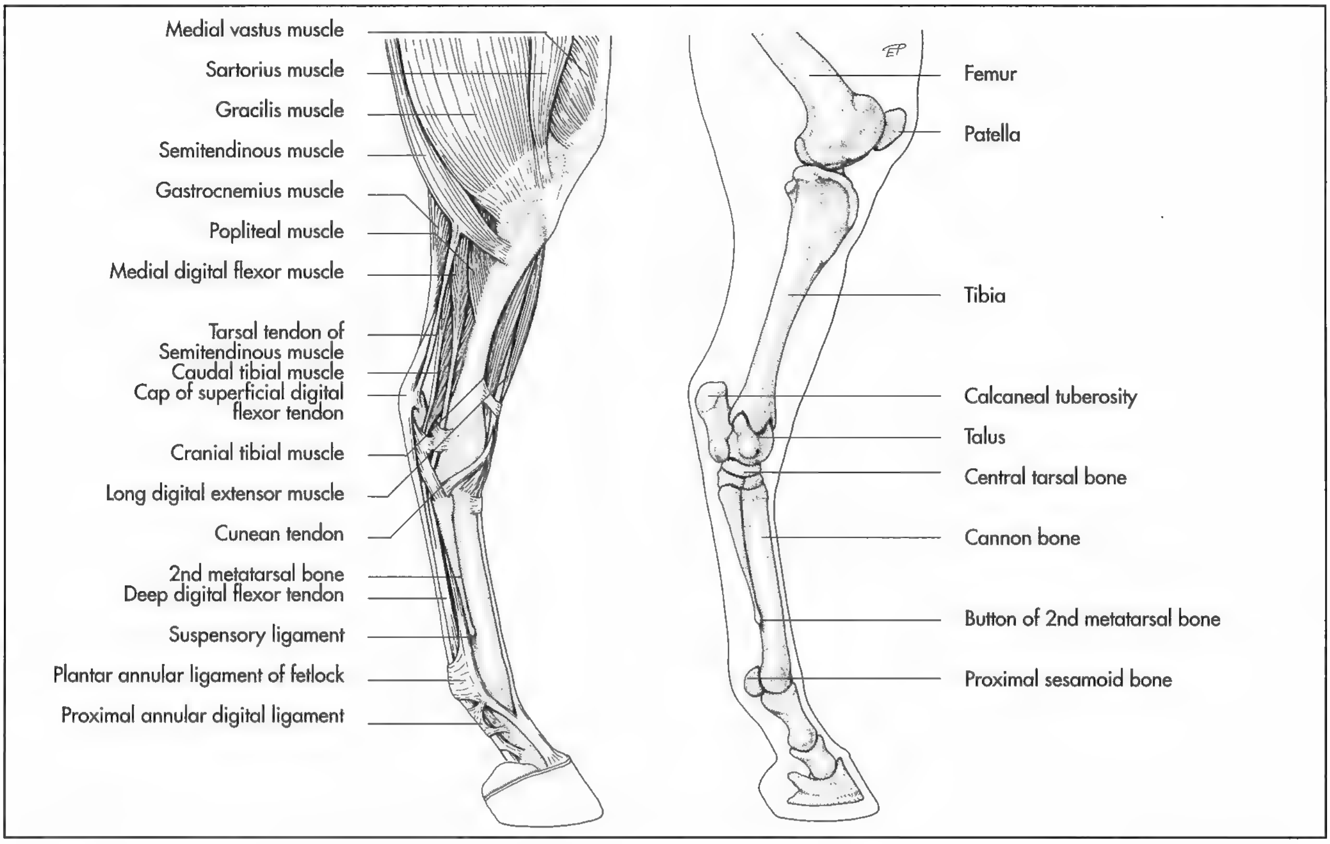

Fig. 4-98. Muscles and skeleton of the hindlimb of the horse (schematic, medial aspect).

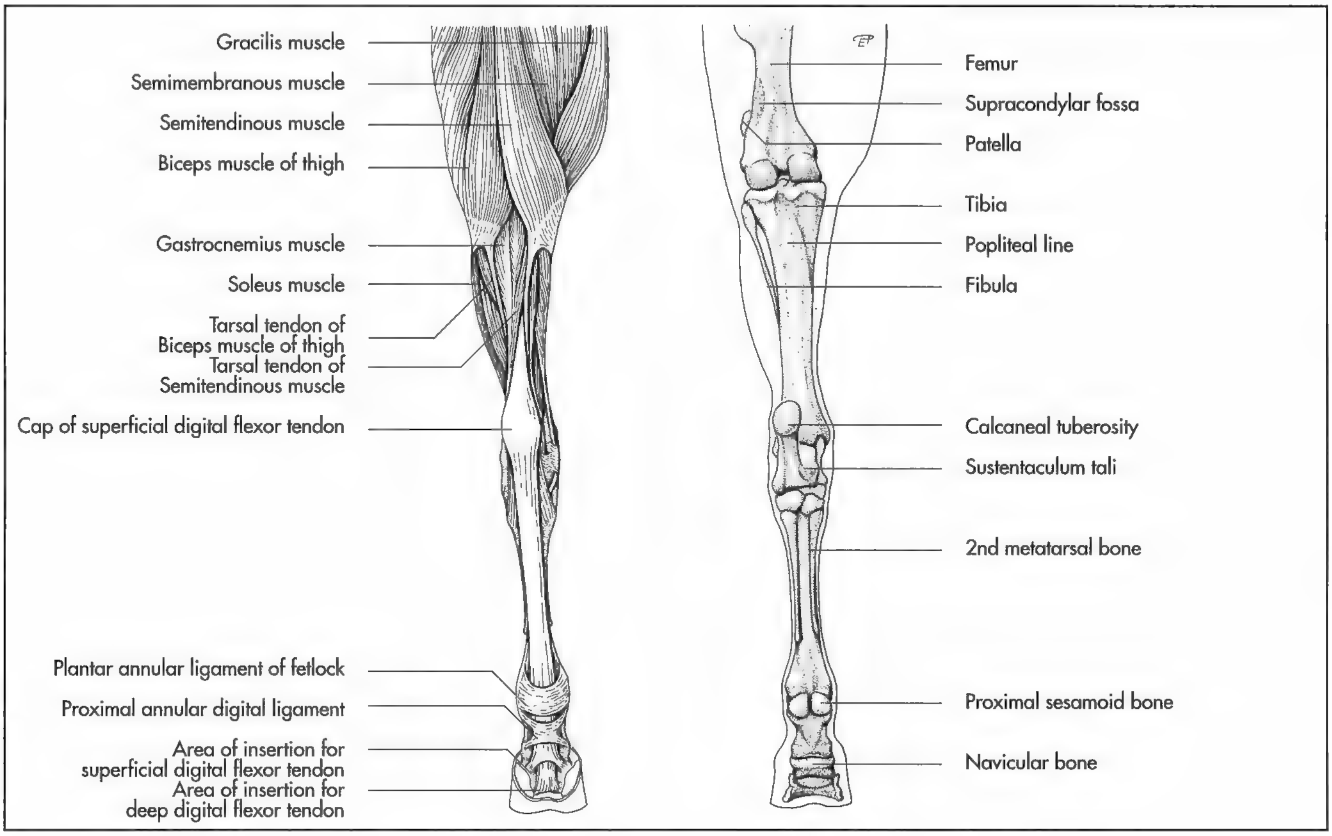

Fig. 4-99. Muscles and skeleton of the hindlimb of the horse (schematic, caudal aspect).

Tab. 4-12. Extensors of the tarsus and flexors of the digits.

Name Innervation	Origin	Insertion	Action
Gastrocnemius muscle Tibial nerve	Distal on femur	Calcaneal tuber (Achilles tendon)	Extensor of the tarsus; flexor of the stifle joint
Soleus muscle Tibial nerve	Fibula	Achilles tendon	Extensor of the tarsus
Superficial digital flexor muscle Tibial nerve	Supracondylar fossa; lateral supracondylar tuberosity	Proximal phalanx and middle phalanx	Flexor of the stifle joint; flexor of the digits; extensor of the tarsus
Deep digital flexor muscle			
Caudal tibial muscle Tibial nerve	Fibula and tibia	Deep digital flexor tendon distal phalanx	Flexor of the digits
Medial digital flexor muscle Tibial nerve	Tibia	Deep digital flexor tendon distal phalanx	Flexor of the digits
Lateral digital flexor muscle Tibial nerve	Fibula and tibia	Deep digital flexor tendon distal phalanx	Flexor of the digits

The **short digital flexor muscle** consists of some muscular fibres in the dog, but a more extensive muscle plate in the cat within the superficial flexor tendon.

The **interflexor muscles** are two muscle bundles in the dog and three in the cat, which are located between the deep and superficial flexor tendons, extending from the middle of the tarsus to metatarsophalangeal joints.

The **interosseous muscles** and **lumbrical muscles** are similar to the corresponding muscles in the thoracic limb.

The **plantar quadrate muscle** is stronger in the cat than in the dog. It arises from the lateral aspect of the calcaneus, extends mediodistally to the deep digital flexor tendon and radiates into the medial digital flexor tendon.

Special muscles of the digits of carnivores

The special muscles of the digits of carnivores are similar to the like-named muscles in the forelimb.

5 Statics and dynamics

J. Maierl, H. E. König and H.-G. Liebich

Animals are subjected to the same physical laws as inanimated objects. **Statics** describes the principles of construction necessary to maintain the **equilibrium of the body** in a state of rest or in motion. **Dynamics** analyses the **movement** of the body during locomotion.

There is a great **adaptive variety** in the construction of the body between different species, reflecting the requirements set forth by their natural surroundings. Carnivores, being predators, must develop considerable speed over a short distance in order to catch their prey, the body of herbivores is specialised to support large stores of poorly digestible food and to enable continuous movement over long distances. These differences are exemplified by the horse, being characterised by passive support mechanisms, which allow the horse to carry heavy loads for a long period of time without the muscles fatiguing. Whereas these support mechanisms have not developed in the dog, which has a lower body weight, whose food is highly digestible and of a higher energy density.

Architecture of the trunk

Previous authors have compared the construction of the body axis with various types of bridges. Recent studies indicate, that this concept is flawed and the more accurate **"bow and string" theory** (Fig. 5-1) is refered to. The **thoracolumbar vertebrae,** their articulations and the accompanying ligaments and muscles provide a flexible structure, constituting the "bow". The "string" consists of the **abdominal muscles,** especially the straight muscle of the abdomen, which reaches from the thorax to the pelvis. The bow is indirectly attached to the string by interposition of the thoracic skeleton cranially and the pelvic bones caudally.

Contraction of the abdominal muscle causes flexion of the bow, while contraction of the epiaxial muscles straightens the bow. Furthermore the weight of the viscera attached to the vertebral column tends to straighten out the bow, while at the same time the weight of the viscera on the abdominal muscles bends the bow. Flexion of the bow is assisted by the protractor muscles of the forelimb and retractor muscles of the hindlimb, while their opposing muscles have the opposite effect. The intrinsic elasticity of the trunk construction is complemented by active contraction of other muscles. This is evident in the horse, when its back does not sag under the rider, but rather is curved in a dorsal direction as a result of the increasing tension in the string. The caudal part of the bow and string construction, the last lumbar vertebra, is joined to the sacrum.

It is possible to extend the "bow and string" theory onto the cervical region, but the curve is in the opposite direction to that of the thoracolumbar region. The **cervical vertebrae** and their articulations constitute the bow, while the **nuchal ligament** acts as the string. The weight and active lowering of the head straightens the "bow", while the nuchal ligament flexes it.

Thoracic limb

The major role of the forelimbs is to support the weight of the body, this is reflected by a reduction in the skeletal structure of the shoulder girdle, where only the scapula and in some species a much reduced clavicle, remain. The scapula is attached to the trunk at the cranial end of the bow and string construction by a synsarcosis, with muscles and tendons forming a sling-like suspension for the trunk. The ventral serrate muscles form a cradle between the two scapulae, which allows the thorax to rise and fall between the shoulders and for the animal to lean over to one side without any corresponding deviation of either forelimb from the perpendicular. The thoracic portion of the ventral serrate muscle, with its high content of tendinous tissue, is well adapted to carry the considerable weight with a minimum of muscular effort. This anatomical arrangement enables the considerable forces which occur during standing and locomotion to be sustained. The forces that the thoracic limbs are subjected to, increase considerably, when the animal contacts the ground after jumping (Fig. 5-2).

Even when an animal is standing still the muscles on either side of each joint are finely adjusting to maintain balance. In large animals this would result in considerable stress in the muscle tissues, thus an increase in fibrous tissue can be found within the muscles of the larger animal, which resists these forces. The movement of the joints is also restricted by the arrangement of fascia and ligaments and the design of the articular surfaces. These structures limit the range of movement of the joints of larger animals to flexion and extension, with the exception of the shoulder and hip joints. In some joints, such as the elbow joint, the collateral ligaments insert eccentrically and thus present a force, which has to be overcome before a joint

Fig. 5-1. "Bow and string" construction in the rearing horse (schematic, the muscles are coloured black), Komarek, 1993.

can be moved. This arrangement prevents flexion caused by depression of the joint from the animal's weight.

The horse has developed tendinous-ligamentous support mechanisms, the **stay apparatus** present in both the forelimbs and hindlimbs, which allow this species to carry its body weight with a minimum of muscular effort and reduce muscle fatigue (Fig. 5-2). The efficient use of this apparatus enables the horse to stand very for long periods whilst resting. True sleep must be accompanied by removal of the weight from the limbs by lying down.

The weight of the body tends to flex the shoulder joint through the insertion of the ventral serrate muscle. Thus can arrangement exists to prevent shoulder flexion, involving isometric contraction of the supraspinous muscle of the forearm and more importantly the biceps brachii muscles, in which tension increases as the shoulder tends to flexes. This can only occur if the biceps brachii muscle is prevented from flexing the elbow joint, which is achieved by two mechanisms. The superficial and deep digital flexor muscles are tensed by the dorsoflexion of the fetlock joint in the normal standing position thus resulting in an increase of passive tension of their inelastic components to maintain elbow extension through their humeral heads. Another key factor in the shoulder / elbow fixation mechanism is the isometric contraction of the triceps (Fig. 5-2).

The carpus is predisposed to effortless weight bearing since the long axis of the radius and the cannon bone are approximately in the same vertical line. It is prevented from buckling forwards by the lacertus fibrosus, an inelastic band arising from the biceps tendon, which inserts on the cannon bone. Tension in the biceps is transmitted through this system to assist in fixed extension of the carpus (Fig. 5-2). Overextension of the carpus is prevented by the ligaments on the caudal aspect of the carpus, the ligaments of the accessory bone and the check ligaments (accessory ligaments of the superficial and deep digital flexor tendons). Both check ligaments are kept under tension by the overextended "neutral" position of the metacarpophalangeal joint.

One of the most essential anatomical features of the stay apparatus is the suspensory ligament on the palmar and plantar aspect of the third metacarpus/metatarsus. It serves as the main support for the fetlock, preventing excessive overextension and reducing concussion of the fetlock during locomotion. The superficial and deep digital flexor tendons supplement the suspensory ligament in this function. They are restricted by the accessory ligament between the distal end of the radius and the superficial digital flexor tendon (proximal check ligament) and the accessory ligament between the carpus and the deep digital flexor tendon (distal check ligament).

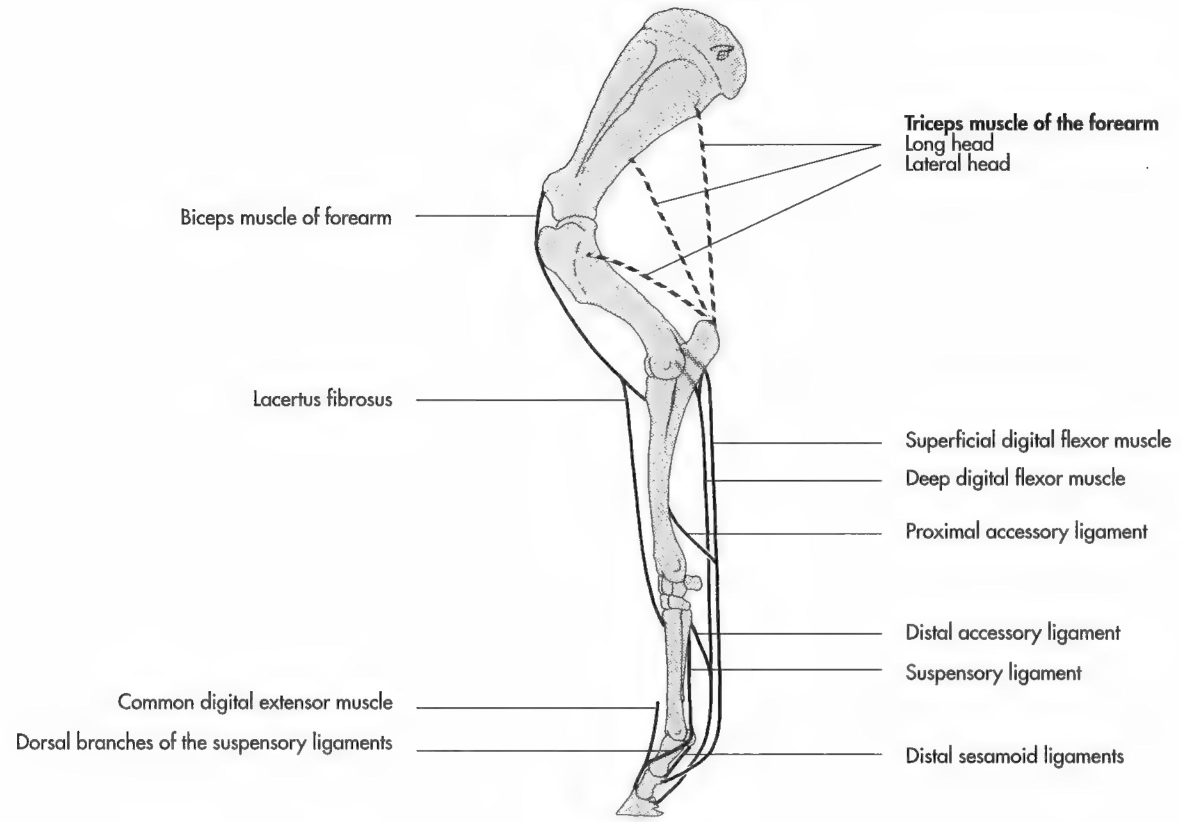

Fig. 5-2. Stay apparatus in the thoracic limb of a horse (schematic).

The suspensory ligament and the two digital flexor tendons operate in series. As the fetlock joint is extended by the bodyweight, the suspensory ligament tightens, this is followed by the superficial and then the deep digital flexor tendon.

During locomotion, the thoracic limb is raised off the ground by the shoulder girdle musculature and the flexion of all joints through their flexor muscles. The flexed limb is protracted by the brachiocephalic muscle. This action is complemented by the trapezius and omotransverse muscles, which rotate the distal end of the scapula craniodorsally and the caudal angle caudoventrally, resulting in the swing phase of locomotion. At the end of the swing phase the joints are extended again, through the action of the triceps muscle of the forearm, the radial extensor muscle of the carpus and digital extensor muscles. This straightens the limb, reaching forward from its starting point, inducing the stance phase of the stride, thus the limb becomes longer and reaches the ground further forward to its starting point. This induces the stance phase of the stride, during which the weight of the body is transported over the extended limb. The scapula is rotated in the reverse direction by the broadest muscle of the back, the rhomboid and the deep pectoral muscle. The triceps is responsible for extending the elbow joint, the biceps muscle extends the shoulder and through the lacertus fibrosus the carpus. The fetlock joint is extended beyond its normal position. Shortly before the limb is lifted off the ground again, the superficial digital flexor tendon and the suspensory ligament are relaxed, while the coffin joint is maximally extended, thus the deep digital flexor tendon and its check ligament are tensed. This causes the phalangeal joints to flex immediately when the foot is lifted off the ground.

Pelvic limb

The sacrum and the pelvis are rigidly attached through the sacroiliac joint, with the sacrum suspended on the inner surface of the ilial wings. This ensures an effective transmission of the thrust of the hindlimb onto the trunk. Since the pelvic limb is responsible for delivering the forward impetus for progression, the musculature of the hindlimb is better developed than the musculature of the forelimb. In the horse many modifications involving **collagenous bands derived from muscular tissue** and **skeletal adaptations** serve to reduce the muscular effort associated with weight bearing and link movement of the hock and stifle joints. The patellar locking mechanism is brought about by the arrangement of the patellar ligaments and the bones, which can result in locking of the

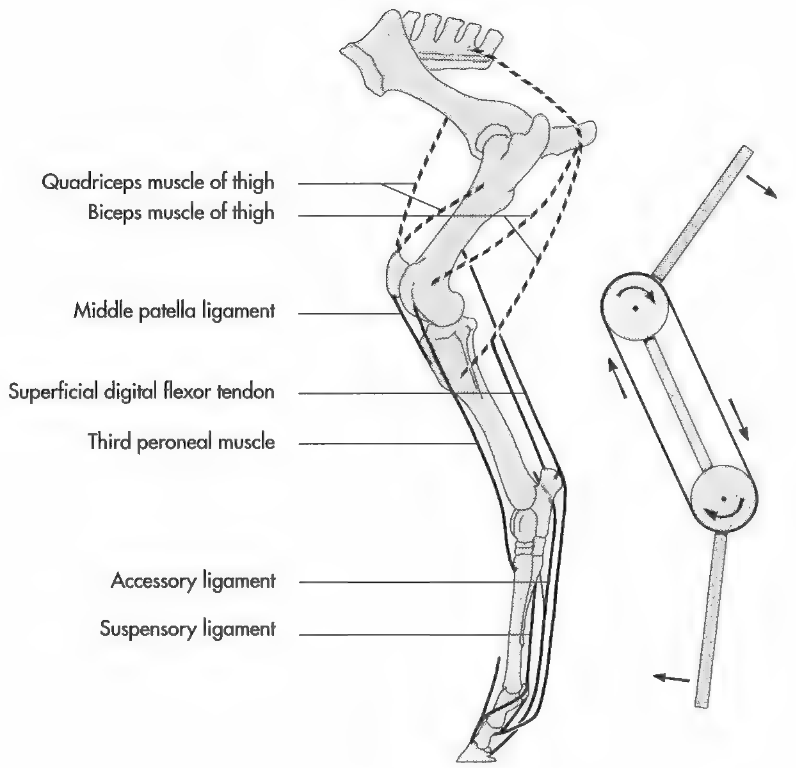

Fig. 5-3. Reciprocal apparatus of the equine hind limb (schematic).

patella and the immobilisation of the stifle and thus the hock. In normal flexion and extension of the stifle joint, the patella glides in the trochlear groove. Extension beyond the proximal extremity of the groove, together with a medial twist of the patella results in the medial ridge of the femur protruding between the medial and the middle patellar ligament. The parapatellar cartilage becomes hooked over the tubercle of the trochlea, thus locking the stifle in an extended position. This mechanism enables the horse to rest its weight on one hindlimb, with a minimum of muscular effort. According to recent studies this locking mechanism is not completely passive. The vastus medialis muscle is actively keeping the medial loop formed by the middle and medial patellar ligament as well as the patella and parapatellar cartilage in position. To release the mechanism, the weight is shifted to the other limb and the quadriceps muscle of the thigh draws the patella proximally. By a slight lateral twist the patella returns to the trochlear groove. If the patella cannot be unlocked or locking occurs during progression the stifle and hock remain locked in extension while the fetlock, pastern and coffin joints are flexed and the horse drags the toe.

Horses with a straight conformation of the hindlimb and Shetland Ponies are thought to be predisposed to upward fixation of the patella.

Another modification, unique to the equine hindlimb is known as the reciprocal apparatus and links the stifle and hock movements (Fig. 5-3). It consists of the third peroneal muscle cranially, opposed by the gastrocnemius and the superficial digital flexor muscle caudally. The attachment of the third peroneal muscle ensures that in the normal animal flexion of the stifle joint must be accompanied by flexion of the hock, while the caudal muscles ensure, that when the stifle joint is extended the hock joint is also extended.

Unlike the carpus, the tarsus is always maintained at an angle. Therefore the superficial flexor tendon requires strong tendinous insertions to stabilise the tarsus in its 'neutral' position.

The fixation and stabilisation of the fetlock joint and the phalangeal joints is similar to the thoracic limb.

The principle of muscle contraction in the hindlimb during locomotion is similar to the thoracic limb. At the beginning of the swing phase the joints of the limb are flexed and the limb moved forward through the contraction of the tensor muscle of the fascia lata, the superficial gluteal muscle, the sartorius muscle and the iliopsoas muscle. The abductionary effect of the iliopsoas muscle is counteracted by the muscles on the medial side of the thigh (sartorius, pectineal, gracilis).

At the end of the swing phase, the joints are extended again. The quadriceps plays an important role, since it stabilises the sti-

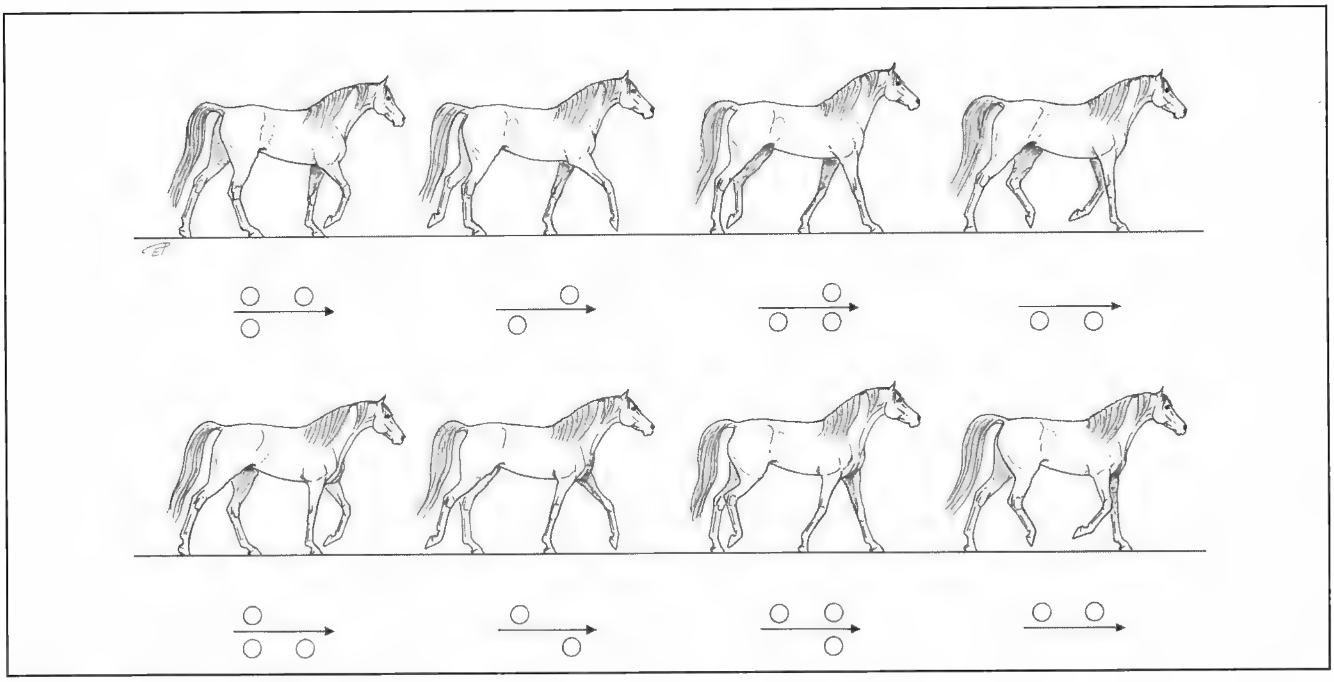

Fig. 5-4. Phases of movement during walking (schematic).

fle. During the stance phase the body is propelled forward through the contraction of the extensors of the hip (medial gluteal muscle), the stifle (quadriceps muscle) and the hock (gastrocnemius muscle), assisted by the hamstring muscles, which hold the stifle caudally relative to the forward moving body.

Movements of the whole body of an animal are the result of the coordinated movements of individual body parts. This can either result in forward, sideward or backward locomotion of the animal or in movements without change in location, such as sitting, lying down, rolling, rising, rearing. Equines have developed a variety of defence mechanisms, such as rearing and kicking, which involve shifting the centre of gravity to free one or two limbs off the ground. During locomotion the limbs are moved in a repetitive and regular sequence, as the result of the cyclic activation of functional groups of muscles. Each stride can be divided in the stance phase, during which the foot is in contact with the ground and in the swing phase, during which the foot is off the ground.

Gaits

Natural gaits include the walk, trot and gallop. Some animals show additional gaits such as pace, amble or rack. In horses each gait can be classified as ordinary, collected or extended. The canter is a collected gallop.

The walk is a four-beat gait. The sequence of hoof beats can be described according to the following pattern: 1. left hind, 2. left fore, 3. right hind, 4. right fore. During the walk two feet are always in contact with the ground, there is no suspension period.

The trot is a two-beat gait in which opposite fore and hind feet hit the ground together. The right forelimb and the left hindlimb move together as do the left fore and the right hind. The extended gallop is a four beat gait, while the collected gallop, the canter, has a three-time pattern. The gallop can be performed with either the left or the right forelimb leading. An animal normally changes leads periodically. Some animals however, especially dogs, change lead in front without changing behind immediately, thus it lands on the hindlimb of the same side as the leading forefoot instead of the opposite hind foot. In a horse with the right-fore leading the sequence is as follows: 1. right fore (suspension), 2. left hind, 3. right hind, 4. left fore. The canter is a three-time gait, which is very similar to the gallop, except that the two paired, non-leading diagonal limbs land together. The single beat of the paired limbs fall between successive beats of the unpaired lead limbs. The sequence in a right-fore lead is the following: 1. right fore (suspension), 2. left hind 3. right hind and left fore together.

Movement backwards is perfomed at the two beat diagonal gait of the trot. Left hind and right fore move together as do right hind and left fore.

Biomechanically the action of the limbs during locomotion can be compared to a pendulum, which show a spring-like compression, when the limb contacts the ground. Latest research has proved that the pendular movements of the limbs during the walk resemble the oscillation of a pendulum, with the same mass distribution. This resonance phenomenon results in a considerable reduction of muscular effort necessary for moving the limb forward. The oscillation time of the limbs become shorter with increasing speed. Increased muscular effort would be necessary to achieve faster oscillation. At a certain speed the animal changes to trot, since this gait uses spring-like mechanisms which achieve faster resonance oscillation with a minimum muscular effort. When the foot hits the

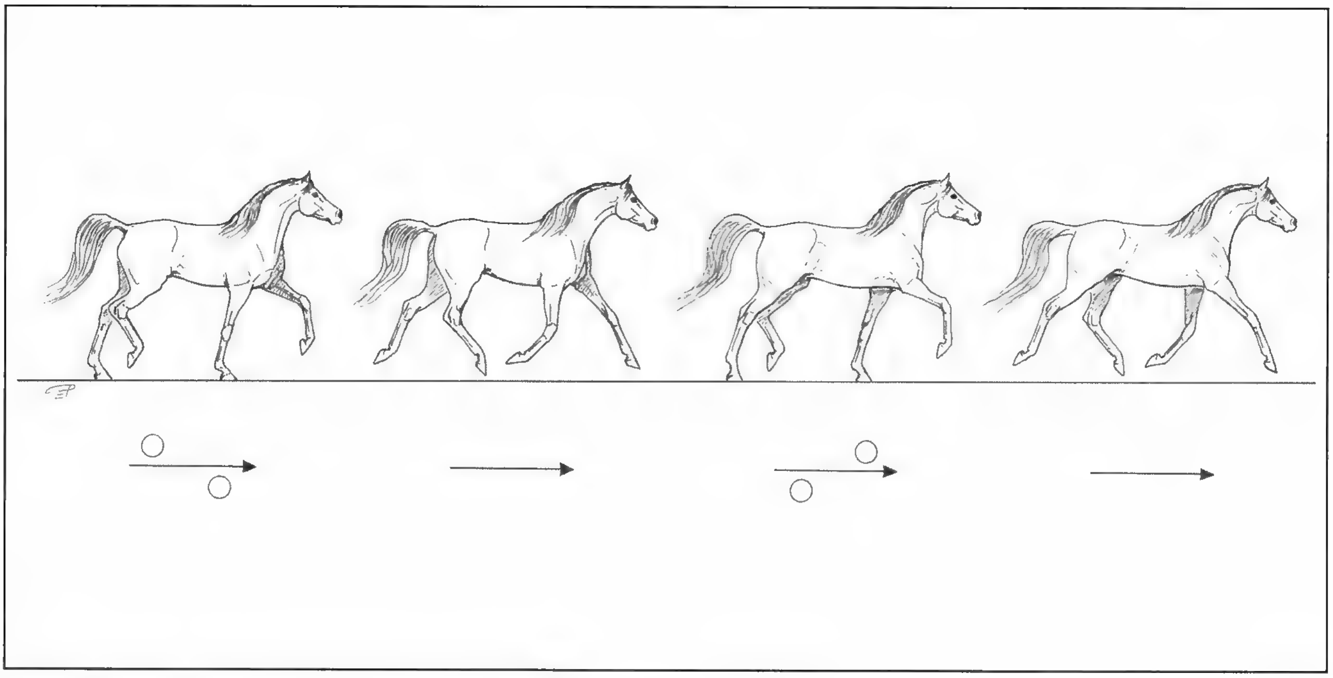

Fig. 5-5. Phases of movement during trotting (schematic).

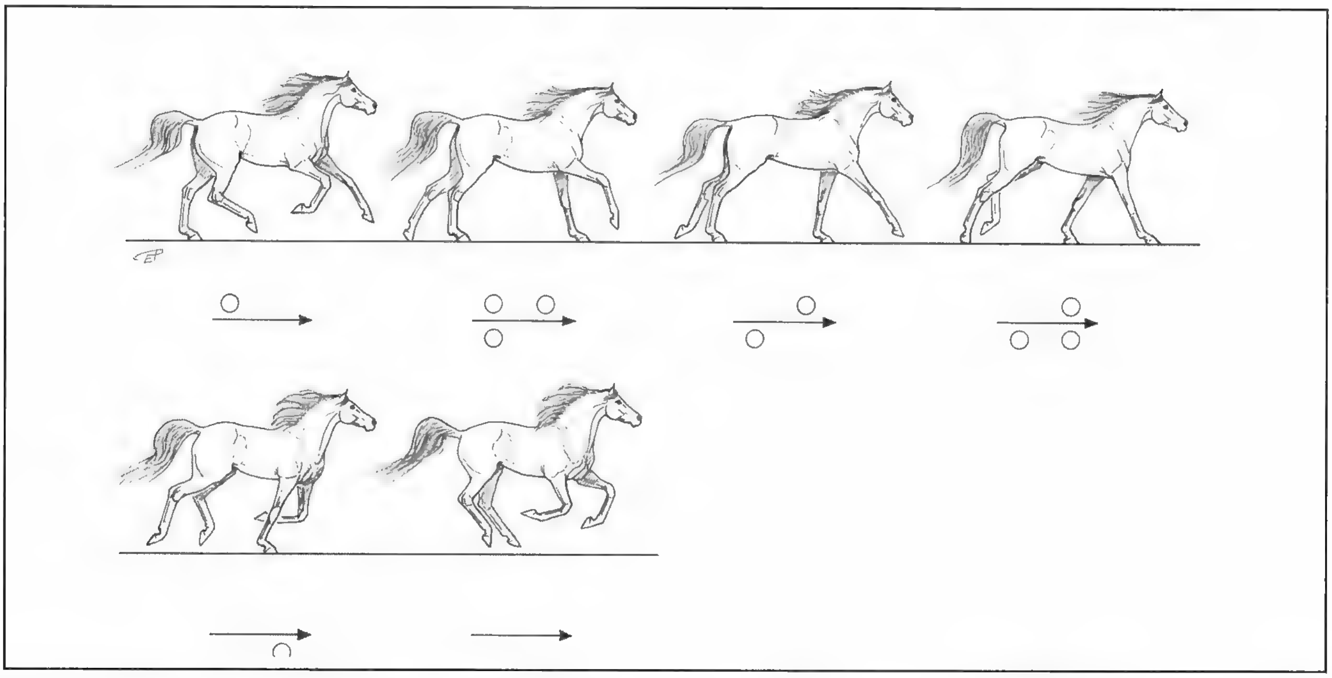

Fig. 5-6. Phases of movement during galloping (schematic).

ground the flexor muscles of the digit are put under tension and are relaxed again, when the foot leaves the ground, these muscles act like paired axial springs. During gallop the resonance oscillation of the limbs become even shorter. Up to three legs can be at the ground at the same time and act as axial springs, similar to the trot. When the animal changes to a faster gait, the duration of a stride becomes shorter and the length increases. This is a result of the described resonance phenomenon, which helps the animal to achieve a certain speed with the least muscular effort.

In addition to the spring mechanisms of the limbs, the rhythmic flexion and extension of the thoracic and lumbar spine assists locomotion.

6 Body cavities

H. E. König and H.-G. Liebich

The body cavities are located within the trunk and can be divided into three different regions, the thorax, the abdomen and the pelvis. In the cavities the organs (viscera) are situated, where they are tightly arranged. Small fluid filled clefts between the organs, allow them to glide freely against each other with a minimum of friction. This lubrication of the smooth surfaces of the organs, together with their flexible attachments, permits movement of the viscera, which is essential for their function (e.g. the movement of the lungs during respiration or the movement of the intestines during digestion).

The body cavities are part of the **trunk,** which can be divided into three parts:

- Thorax,
- Abdomen and
- Pelvis.

With the early embryonic development of the musculotendinous diaphragm the body cavity is divided into:

- Thoracic cavity (cavum pectoris),
- Abdominal cavity (cavum abdominis) in continuation
- with the pelvic cavities (cavum pelvis).

The **thoracic** and **abdominal cavities** communicate via three openings within the diaphragm: the **esophageal hiatus,** through which the oesophagus, vagal nerve trunks and the oesophageal vessels pass; the **caval foramen,** through which the caudal vena cava passes and the **aortic hiatus,** through which the aorta, the thoracic duct and the azygos and hemiazygos veins pass. The sympathetic trunk and splanchnic nerves pass dorsal to the lumbocostal arch on each side.

The **pelvic cavity** is a direct continuation of the abdominal cavity. The division between the two is the pelvic inlet and is marked by the terminal line, which extends from the promontory of the sacrum to the arcuate lines of both ilia and the pectineal line of the pubis. The walls of the body cavities have a common architecture, which show a few modifications depending on the body region.

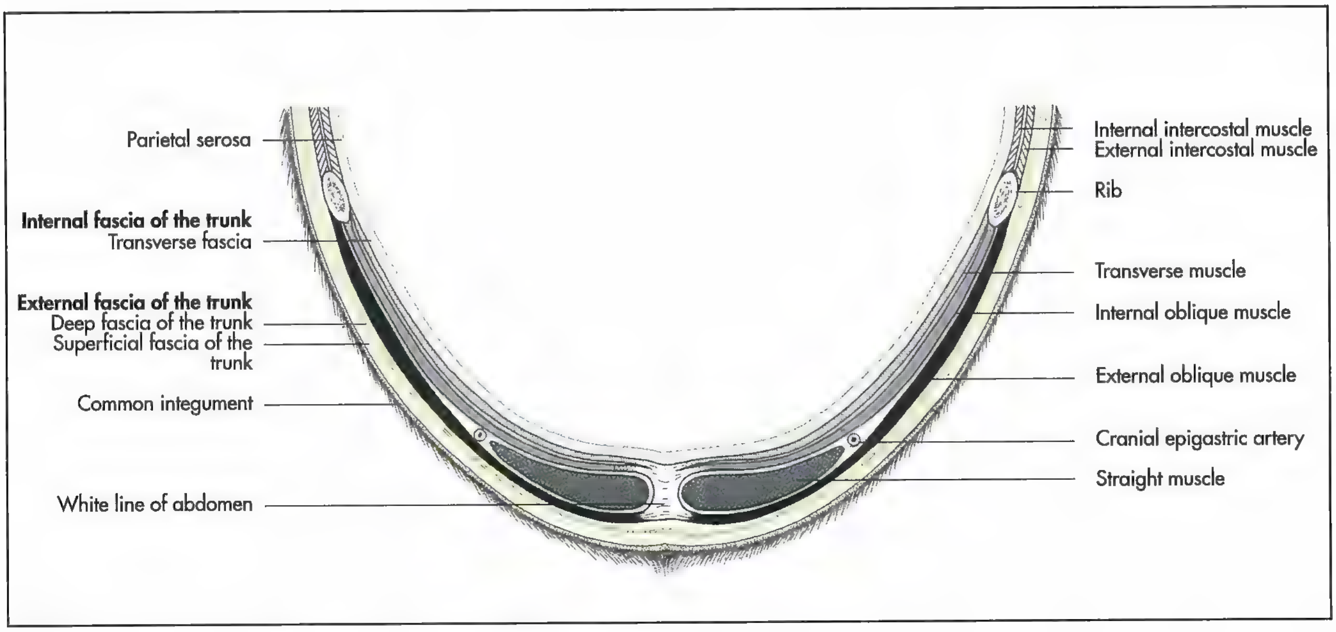

Abb. 6-1. Layers of the abdominal wall, schematic (transverse section).

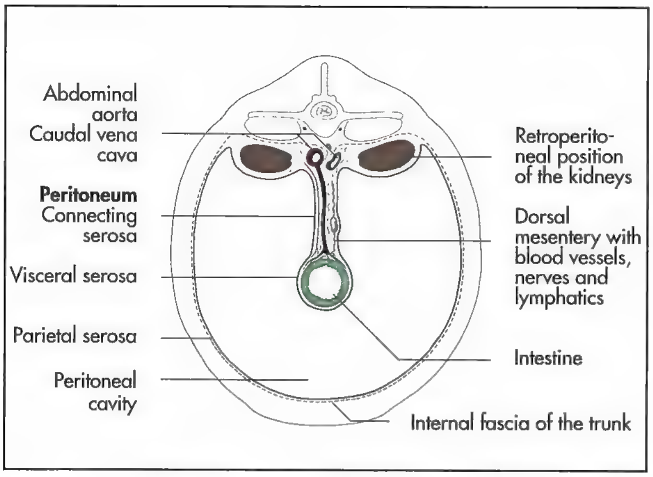

Abb. 6-2. Peritoneum, schematic.

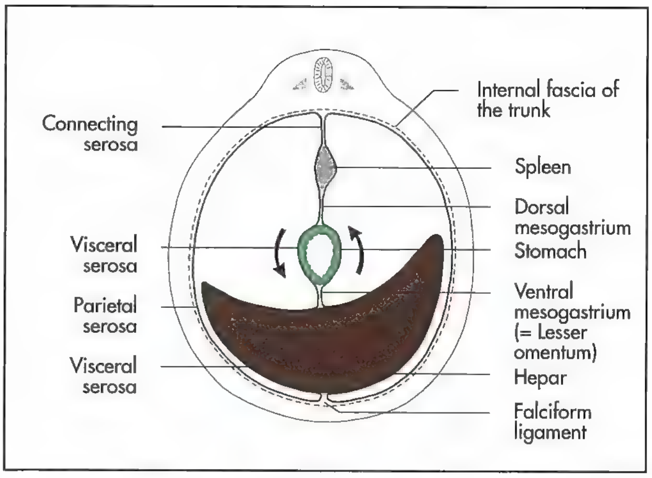

Abb. 6-3. Embryonic development of the dorsal and ventral mesogastrium, schematic.

In general, it is composed of the following layers, starting externally:

- Common integument (integumentum commune),
- Superficial fascia of the trunk (fascia trunci externa),
- Skeletal muscles,
- Deep fascia of the trunk (fascia trunci interna) and
- Serosa or serous membrane (tunica serosa).

Serous membranes consist of a surface mesothelium composed of a single layer of squamous cells (lamina epithelialis serosa, mesothelium) and a connective tissue stroma (lamina propria serosae). Serous membranes have the ability to produce and absorb serous fluid and also to absorb air or gasses (such as carbon dioxide after laporoscopic surgery). The **serous fluid** contains physiological buffers, epithelial cells and cells of the immune system. Together with the mesothelium they provide a functional barrier, which is of considerable clinical importance.

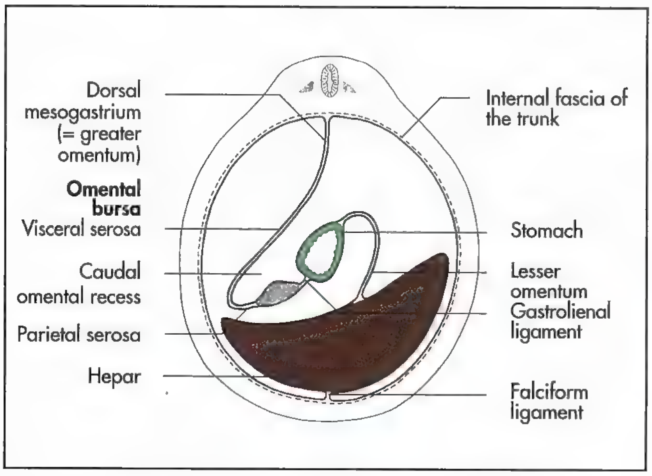

Abb. 6-4. Embryonic development of the greater and lesser omentum, schematic.

As well as lining the body cavities, serosal membranes form a continuous membrane covering the viscera (Fig. 6-1 to 8) in healthy animals they appear **smooth, transparent** and **shiny.** There are four serosal cavities:

- Left and right pleural cavities (cavum pleurae) formed by the pleura,
- Pericardial cavity (cavum pericardii) formed by the serous pericardium,
- Peritoneal cavity (cavum peritonei) formed by the peritoneum.

The **serous membranes** are connected to the underlying deep fascia by areolar tissue, known as the **tela subserosa.** This layer contains fat, blood and lymphatic vessels. Underlying the epithelium there is a fine network of nerves, which are sensitive to tactile, mechanical, thermal and chemical stimuli.

The tela subserosa creates a narrow retroserosal space between the serous membranes and the body cavities. This space is widest between the peritoneum and the dorsal wall of the abdomen and on the floor of the pelvis, forming the retroperitoneal space. Organs within this space such as the kidneys and the ureters are covered only on one surface by peritoneum and are said to be retroperitoneal. These organs can be reached surgically without opening the peritoneal cavity.

Organs that project freely into the abdominal, pelvic or thoracic cavity have a complete covering of serosa and are termed intraperitoneal or intrapleural respectively.

Serous membranes (Fig. 6-1 to 4) can be divided into:

- Parietal serosa (serosa seu lamina parietalis),
- Connecting serosa (serosa seu lamina intermedia),
- Visceral serosa (serosa seu lamina visceralis).

The **parietal serosa** covers a large part of the inner surfaces of the body wall and is always connected to the underlying fascia by loose connective tissue. Depending on the location it is called:

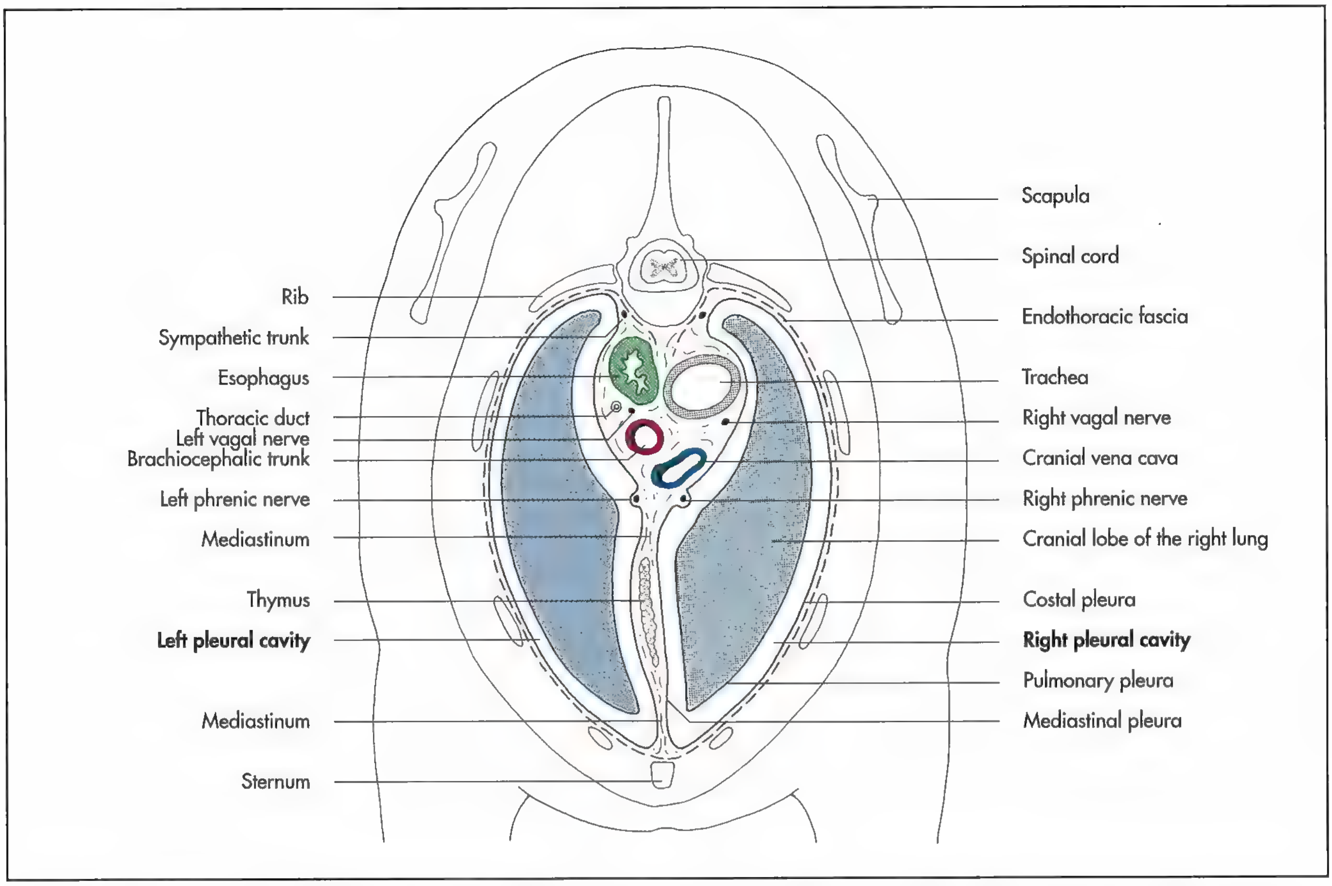

Fig. 6-5. Transverse section of the canine thorax at the level of the cranial mediastinum, caudal aspect, serosal clefts enlarged, schematic.

- Parietal pleura in the thorax,
- Parietal peritoneum in the abdomen and pelvis.

Unlike the connecting and visceral layers, the parietal serosa is extremely susceptible to pain, which necessitates careful local anaesthesia of the abdominal wall prior to surgery.

The prefix "peri" in front of the name of an organ indicates which organ the serosa encloses (for example pericardium for the parietal serosa enclosing the heart).

The **connecting serosa** consists of double sheets of serosal membranes extending between organs or connecting organs to the parietal serosa. They are usually referred to as mesenteries, but they also form the omenta and ligaments. **Mesenteries** are serous folds, which attach organs to the body walls. They supply routes for blood vessels and nerves, in many cases contain lymph nodes and keep organs in their place.

The mesenteries can be divided into **ventral** and **dorsal parts.** The prefix "meso" at the beginning of the name of an organ indicates, which organ this serosal fold connects to the body wall (for example "mesogastrium" for the attachment of the stomach).

The **visceral serosa** extends from the dorsal body wall as **double sheets** of connecting serosa and covers the intrapleural and intraabdominal organs (Fig. 6-2). The prefix "epi" is used to indicate the visceral serosa of an organ (for example "epicardium" covering the myocardium of the heart). In the thoracic cavity and in the cranial parts of the abdominal cavity the two separate visceral membranes unite again to form an additional connecting serosa, which attaches to the ventral body wall. Caudal parts of the intestine do not have a ventral attachment due to their embryonic development.

Special derivatives of the peritoneum are the greater and lesser omentum. The **greater omentum** (omentum majus) develops from the dorsal mesentery of the stomach (mesogastrium dorsale). The dorsal mesogastrium is drawn out and folded on it forming a pouch, the **omental bursa,** which encloses the **caudal omental recess** (recessus caudalis omentalis). It originates from the dorsal wall of the abdomen, turns caudally between the viscera and the abdominal floor to the pelvic inlet in ruminants and carnivores, where it reflects back to reach the major curvature of the stomach. Its walls are described as parietal (ventral) and visceral (dorsal) because of their relationship to abdominal wall and viscera. Communication between the omental bursa and the major part of the peritoneal cavity is restricted to a narrow opening, the **epiploic foramen** (Fig. 7-63).

In addition to the greater omentum there are several double-layered peritoneal folds extending between neighbouring organs, which are also derived from the dorsal mesogastrium. These folds restrict mobility of these organs and create spaces, such as the nephrosplenic space in the horse, in which parts of the intestines may become trapped. The **lesser omentum** (omentum minus) is derived from the ventral mesogas-

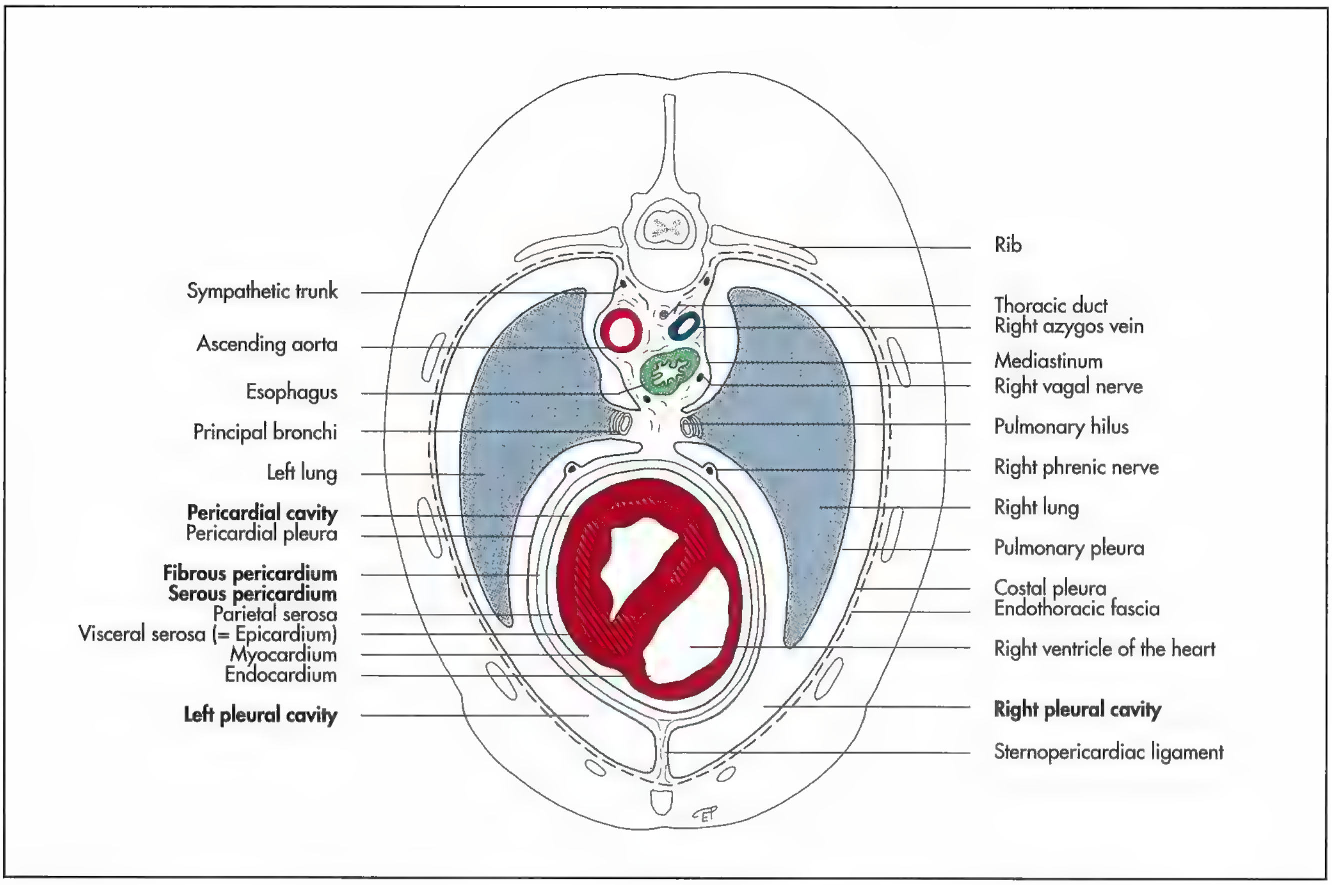

Fig. 6-6. Transverse section of the canine thorax at the level of the medial mediastinum, caudal aspect, serosal clefts enlarged, schematic.

Fig. 6-7. Transverse computed tomogram of the cranial part of a canine thorax (courtesy of Dr. A. Probst, Vienna).

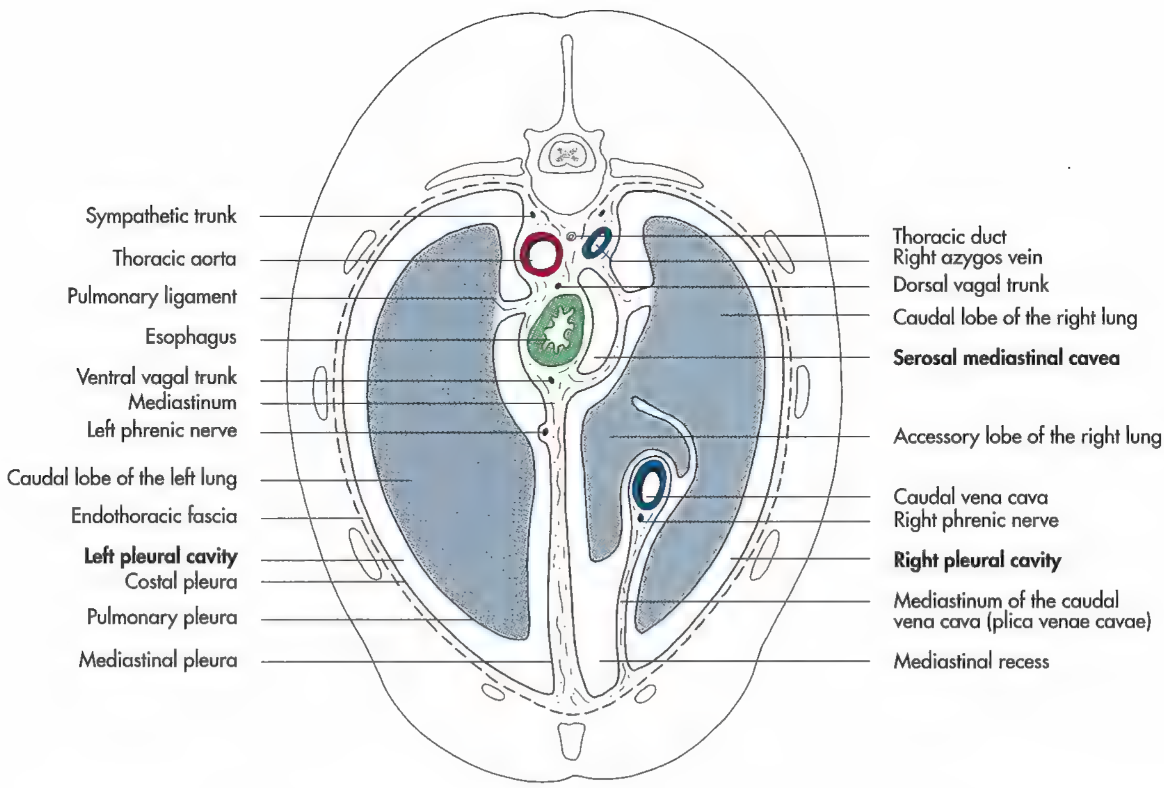

Fig. 6-8. Transverse section of the canine thorax at the level of the caudal mediastinum, caudal aspect, serosal clefts enlarged, schematic.

trium (Fig. 6-3). It is continuous with the cranial mesoduodenum and has a close relationship to the liver. It forms the ventral attachment on the visceral surface of the liver (ligamentum hepatogastricum, ligamentum hepatoduodenale) and continues as the falciform ligament to the abdominal floor (for exact description see chapter 7).

Thoracic cavity (cavum thoracis)

The thoracic cavity is located within the thoracic cage and extends from the **cranial thoracic inlet** (apertura thoracis cranialis), bounded laterally by the first pair of ribs to the **caudal thoracic outlet** (apertura thoracis caudalis).

The part of the thoracic cavity cranial to the diaphragm is called **pectoral cavity** (cavum pectoris) and the part caudal to the diaphragm is referred to as the intrathoracal part of the abdominal cavity.

The serous membranes within the pectoral cavity are termed **pleura.** The pleura covers the lungs and the walls of the pectoral cavity, thus forming two complete sacs, one on either side, the **pleural cavities** (cavum pleurae). In the healthy animals these sacs contain only a thin film of fluid between the pulmonary pleura and the parietal pleura. The space between the left and the right sac forms the **mediastinum,** in which the heart and other thoracic organs are situated (Fig. 6-5). The cranial aspect of the diaphragm is also covered by pleura. The pleurae can be subdivided, based on the structure it covers:

- **Parietal pleura,** which is further subdivided into
  - Costal pleura,
  - Mediastinal pleura, includes precardial, pericardial and postcardial pleura,
  - Diaphragmatic pleura and
- **Visceral** or **pulmonary pleura.**

The pleurae are attached to underlying muscles, ligaments and bones by areolar tissue, the endothoracic fascia. The endothoracic fascia is also present in the mediastinal space, where it becomes the connective tissue, which invests the organs and other structures in the mediastinum (Fig. 6-5 to 12).

Several spaces are formed by the pleura:

- Mediastinal recess (recessus mediastini),
- Costodiaphragmatic recess (recessus costodiaphragmaticus) and
- Pleural cupula (cupulae pleurae).

The **costodiaphragmatic recesses** are the spaces between the diaphragm and the caudal lateral wall of the thoracic wall.

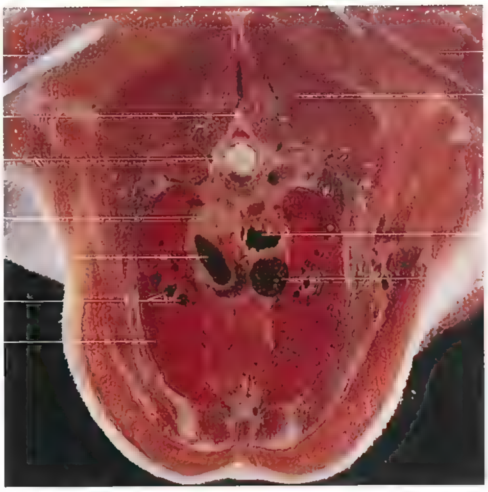

Fig. 6-9. Transverse section of feline thorax at the level of the cranial mediastinum, caudal aspect (König, 1992).

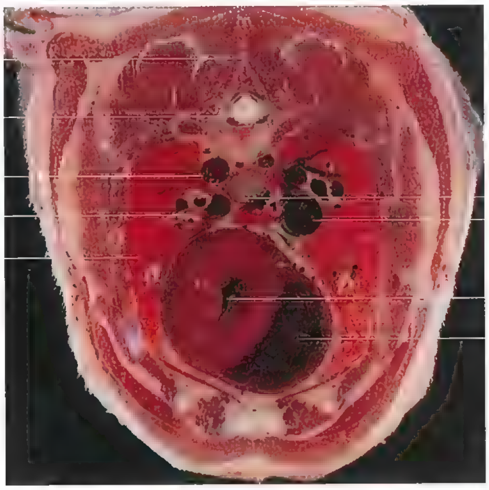

Fig. 6-10. Transverse section of feline thorax at the level of the middle mediastinum, caudal aspect (König, 1992).

Fig. 6-11. Transverse section of feline thorax at the level of the caudal mediastinum, caudal aspect (König, 1992).

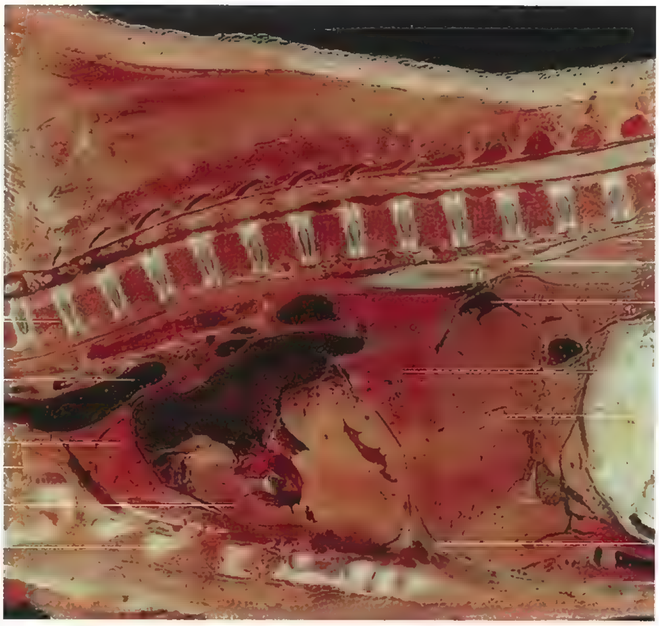

Fig. 6-12. Paramedian section of the thorax of a juvenile pig.

The acute border of the lungs occupies them. The cranial portion of each pleural sac forms a dome-shaped space, the **pleural cupula** (cupulae pleurae).

A thin loose fold of pleura surrounds the caudal vena cava. It forms the **mediastinal recess** (recessus mediastini), in which the accessory lobe of the right lung lies.

Mediastinum

The mediastinum is the space between the left and right pleural sacs (Fig. 6-5, 6-6 and 6-7). It can be divided into three parts:

- Cranial or precardial mediastinum,
- Middle or pericardial mediastinum and
- Caudal or postcardial mediastinum.

The thoracic inlet marks the beginning of the **cranial mediastinum** (mediastinum craniale) (Fig. 6-5 and 6-9). Several vital structures exit the thorax through this part of the mediastinum, and pass towards the head, neck, thoracic limbs and cranial parts of the thoracic wall.

The following nerves, arteries, veins and lymphatics can be found in the cranial mediastinum:

- Brachiocephalic trunk (truncus brachiocephalicus),
- Left and right subclavian artery (a. subclavia sinistra et dextra),
- Left and right costocervical trunk (truncus costocervicalis sinister et dexter),
- Bicarotid trunk (truncus bicaroticus),
- Left and right internal thoracic artery (a. thoracica interna sinistra et dextra),
- Cranial vena cava (v. cava cranialis),
- Left and right sympathetic trunk (truncus sympathicus sinister et dexter),
- Stellate ganglia (ganglion stellatum seu cervicothoracicum sinistrum et dextrum),
- Left and right vagal nerve (n. vagus sinister et dexter),
- Left and right phrenic nerve (n. phrenicus sinister et dexter),
- Left and right recurrent laryngeal nerve (n. laryngeus caud. seu recurrens sinister et dexter) and
- Thoracic duct (ductus thoracicus).

The sternal and cranial mediastinal **lymph nodes** lie within the cranial mediastinal space and in juvenile animals the thymus is present. Above the **trachea** and the **esophagus** the mediastinal pleura covers the sides of the long muscle of the neck (m. longus colli) and reflects onto the thoracic walls as the costal pleura.

The **middle** or **pericardial mediastinum** (mediastinum medium seu cardiale) encloses the heart within the pericardium, the origin of the major blood vessels at the base of the heart, the thoracic duct, the esophagus and the trachea. It may also enclose part of the **thymus gland** in juvenile animals. The trachea bifurcates at the level of the fifth intercostal space forming the two main bronchi. Shortly before this bifurcation the tracheal bronchus leaves the trachea to the right in the pig and ruminants. Structures located in the **middle mediastinal** space are (Fig. 6-6):

- Ascending aorta (aorta ascendens) with the aortic arch (arcus aorticus),
- Pulmonary trunk (truncus pulmonalis),
- Azygos vein (v. azygos),
- Pulmonary veins (vv. pulmonales),

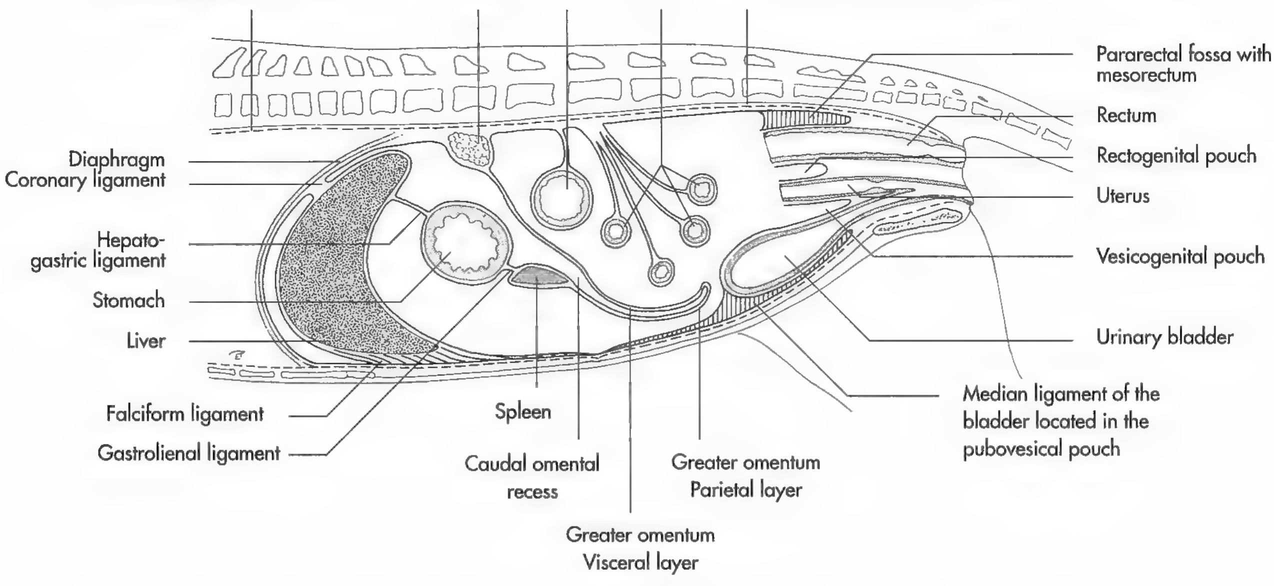

Fig. 6-13. Median section of the abdominal and pelvic cavity of a cat to show the disposition of the peritoneum, schematic.

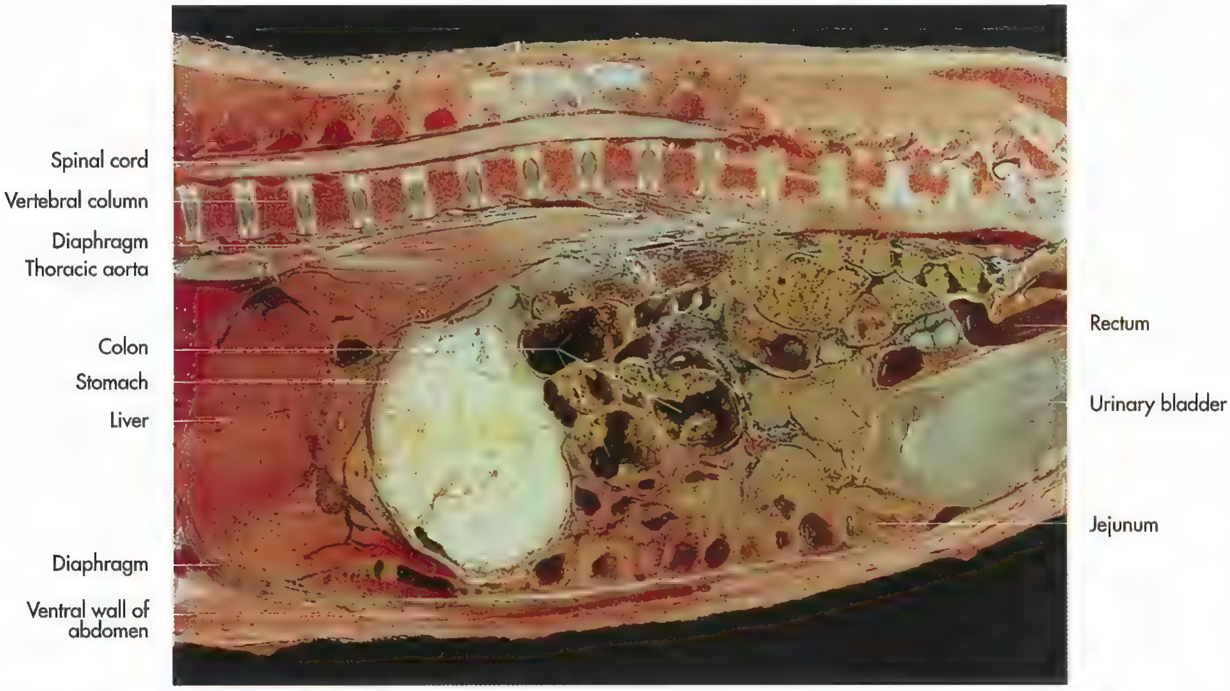

Fig. 6-14. Paramedian section of the abdominal cavity of a juvenile pig.

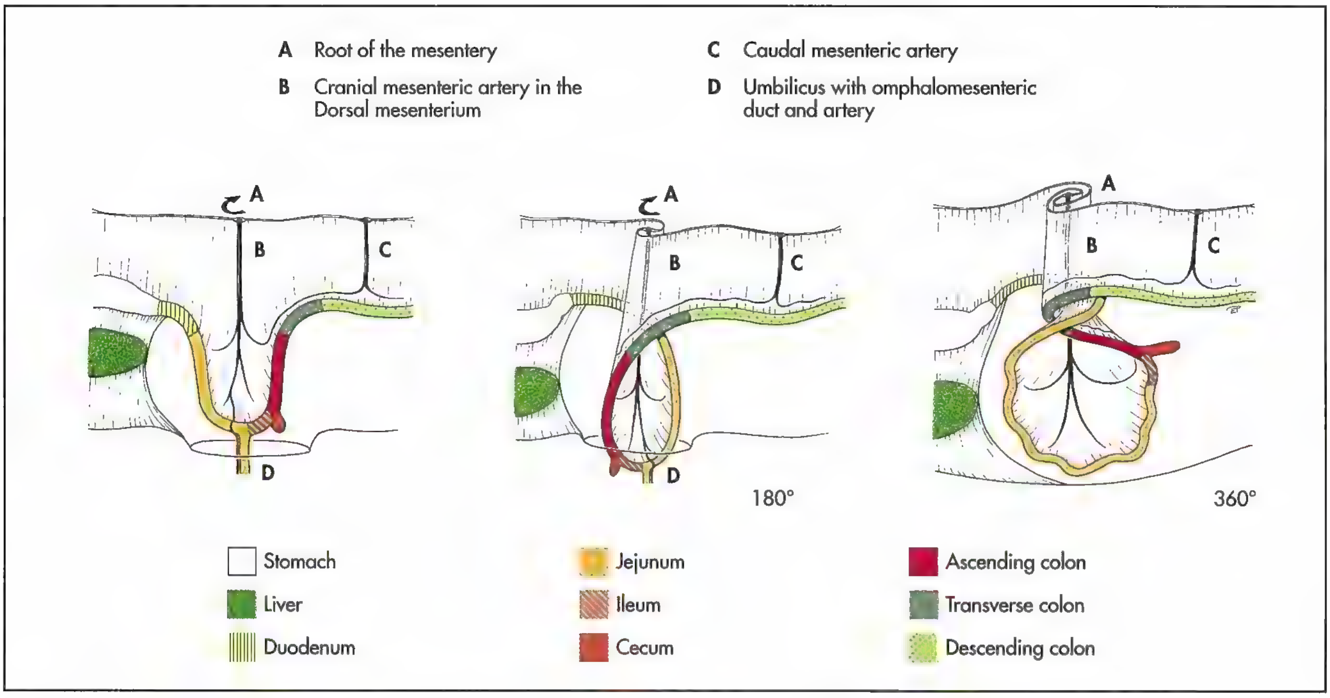

Fig. 6-15. Rotation of the intestine during fetal development.

- Cranial vena cava (v. cava cranialis),
- Caudal vena cava (v. cava caudalis),
- Bronchoesophageal trunk (truncus bronchoesophageus),
- Thoracic duct (ductus thoracicus),
- Left and right internal thoracic vein, (v. thoracica interna sinistra et dextra),
- Left and right vagal nerve (n. vagus sinister et dexter),
- Left and right phrenic nerve (n. phrenicus dexter et sinister) and
- Left and right recurrent laryngeal nerve (n. laryngeus caudalis seu recurrens sinister).

The **caudal** or **postcardial mediastinum** is the space between the heart and the diaphragm (Fig. 6-8 and 6-11). The aorta passes towards the diaphragm dorsally; beneath the aorta runs the oesophagus accompanied by the dorsal and ventral vagal trunk. Immediately next to the caudal mediastinum passes the left **phrenic nerve.**

The caudal lobes of the lungs are attached to the caudal mediastinum and the diaphragm by means of a pleural fold on each side, the left and right **pulmonary ligament** (ligamentum pulmonale). The **serosal mediastinal cavea** (cavum mediastini serosum) is enclosed by the right pulmonary ligament which is more spacious in carnivores and the pig compared to the rest of the domestic mammals (Fig. 6-8).

The following nerves and vessels also pass through the **caudal mediastinum:**

- Thoracic aorta (aorta thoracica),
- Azygos vein (v. azygos),
- Left and right sympathetic trunk (truncus sympathicus sinister et dexter),
- Left and right major and minor splanchnic nerve (n. splanchnicus major et minor sinister et dexter),
- Thoracic duct (ductus thoracicus),
- Dorsal and ventral vagal trunk (truncus vagalis dorsalis et ventralis),
- Left phrenic nerve (n. phrenicus sinister), the right phrenic nerve runs within the plica venae cavae,
- Caudal vena cava to the right of the mediastinum and
- Left and right internal thoracic artery (a. thoracica interna sinistra et dextra).

In the horse and in cachexic dogs the left and right pleural cavities communicate through a fenestration of the caudal mediastinum.

The **caudal vena cava** runs, together with the right phrenic nerve, to the right of the mediastinum in a thin, loose pleural fold referred to as **plica venae cavae** (Fig. 6-8). This plica forms the **mediastinal recess** (recessus mediastini), which completely (horse and ruminants) or partly (carnivores and pigs) contains the accessory lobe of the right lung. The mediastinal recess is bordered by the pericardium cranially, the diaphragm caudally, the mediastinum to the left and the caudal vena cava and its mesentery to the right (Fig. 6-8).

Lymph nodes of the mediastinum

The lymph nodes of the mediastinum can be grouped according to their location into **cranial, middle** and **caudal medias-**

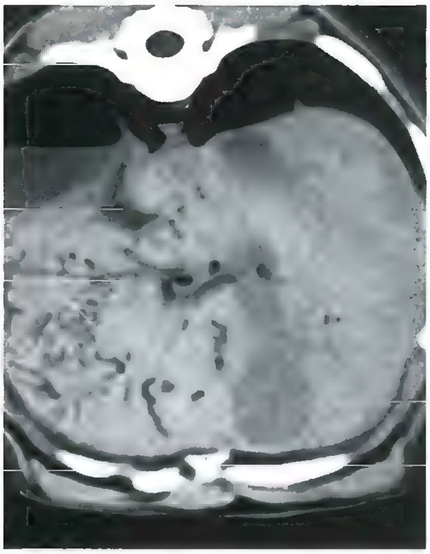

Fig. 6-16. Transverse computer tomogram of the cranial abdominal region of a dog (courtesy of Dr. A. Probst, Vienna).

tinal lymph nodes (lymphonodi mediastinales craniales, medii, and caudales). While the caudal mediastinal lymph nodes are absent in carnivores, they are composed of several substantial lymph nodes in ruminants between the aorta and the esophagus. The **bronchial lymph nodes,** adjacent to the hilus of the lung, can be subdivided into right, middle and left **tracheo-bronchial lymph nodes** (lymphonodi tracheobronchales dextri, medii et sinistri). In the species, which have a tracheal bronchus (ruminants and pigs) there are additional lymph nodes, the **cranial tracheobronchial lymph nodes,** adjacent to this bronchus.

Abdominal and pelvic cavity (cavum abdominis et pelvis)

The abdominal cavity and the cranial part of the pelvic cavity are lined by a serous membrane, the **peritoneum,** forming a sac, which encloses the **peritoneal cavity** (cavum peritonei). Underlying the peritoneum is the internal fascia of the trunk. The abdominal cavity extends from the diaphragm to the pelvic inlet, which is marked by the terminal line of the pelvis. The most cranial part of the abdominal cavity extends

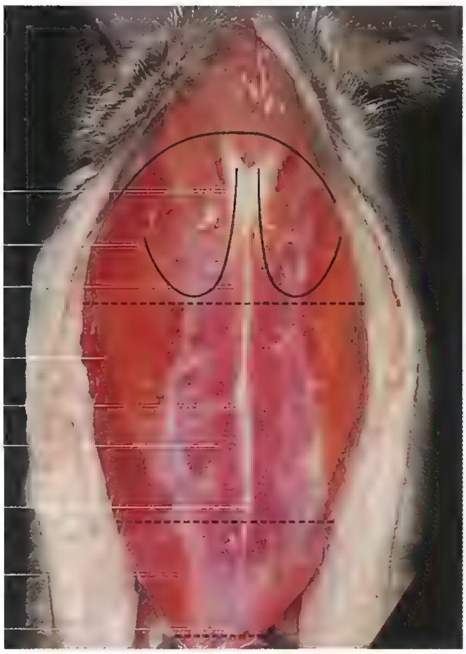

Fig. 6-17. Regions of the ventral abdomen shown on a cat (König, 1992).

Fig. 6-18. Abdominal cavity of a cat (König, 1992).

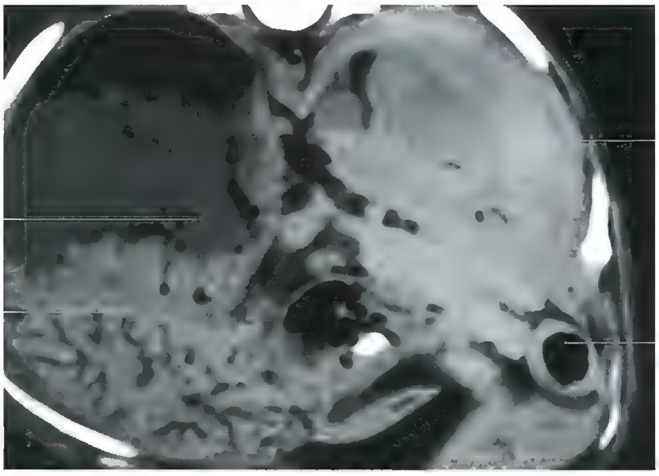

Fig. 6-19. Transverse computer tomogram of the cranial part of the middle abdominal region of a dog (courtesy of Dr. A. Probst, Vienna).

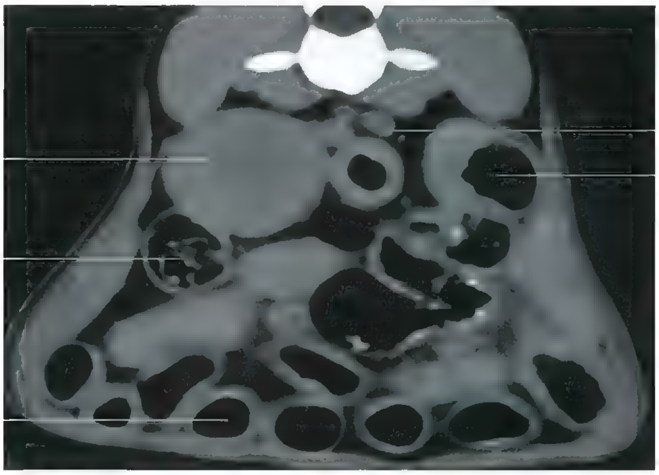

Fig. 6-20. Transverse computer tomogram of the caudal part of the middle abdominal region of a dog (courtesy of Dr. A. Probst, Vienna).

into the thorax and is therefore termed the **intrathoracic part** of the abdominal cavity. To facilitate the description of the abdomen, it can be divided into three main regions:

- Cranial abdominal region (regio abdominis cranialis) or epigastrium,
- Middle abdominal region (regio abdominis media) or mesogastrium,
- Caudal abdominal region (regio abdominis caudalis) or hypogastrium.

The **cranial abdominal region** extends from the diaphragm to an imaginary line between the most caudal part of the costal arch and practically forms the intrathoracic part of the abdominal cavity. The regions caudolateral to the costal arches are termed the **hypochondrial region** (regio hypochondriaca), the region around the xiphoid cartilage, is referred to as the **xiphoid region** (regio xiphoidea) (Fig. 6-17). The **middle abdominal** region extends from the cranial abdominal region to an imaginary line between the tuber sacrale.

This region can be further subdivided into:

- Lumbar region (regio lumbalis) dorsally,
- Lateral abdominal region (regio abdominalis lateralis) or flank laterally,
- Umbilical region (regio umbilicalis) ventrally.

The **paralumbar fossa** (fossa paralumbalis) is located in the dorsal part of the lateral abdominal region bordered by the transverse processes of the lumbar vertebrae, the medial angle of the ilium and the last rib. The **caudal abdominal region** extends from the middle abdominal region to the terminal line, from which the pelvic region continues caudally. The ventral wall of the abdomen is also divided into regions, which makes it easier to describe surgical approaches. The **pubic region** is the area cranial to the pectineal line of the pubis; the **inguinal region** is lateral to the pubic region and extends to the popliteal region. During prenatal development the ventral wall of the abdomen is perforated by the umbilicus (Fig. 6-14), through which parts of the intestine pass during

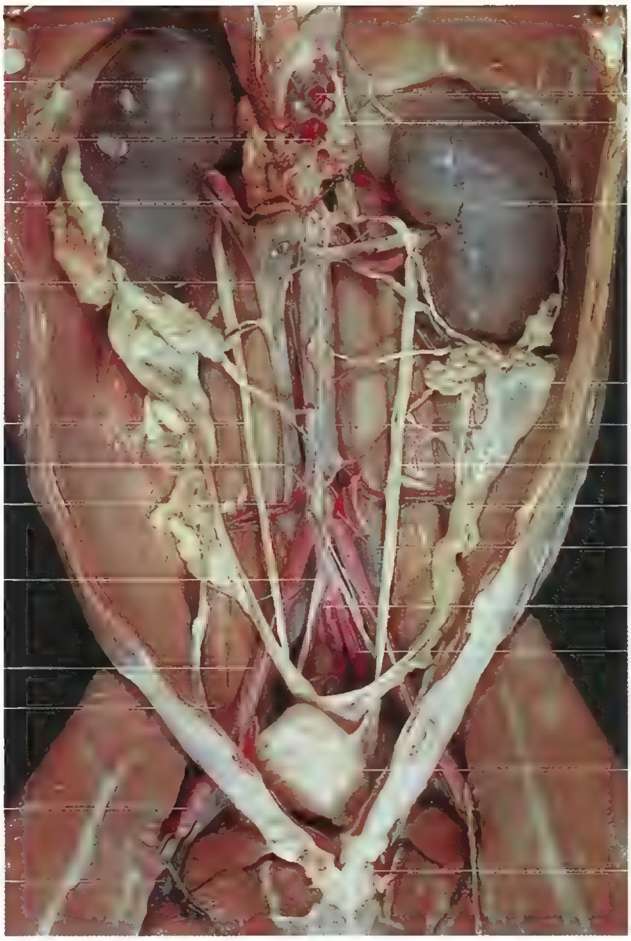

Fig. 6-21. Retroperitoneal muscles and organs on the dorsal wall of the abdomen of a bitch, ventral aspect.

certain stages of foetal development and become situated outside the foetal body cavity. This is referred to as a **physiological umbilical hernia.** The **umbilicus** (greek: omphalos) closes in the first few days post partum. While the umbilicus remains open, ascending infections can pass along the umbilical vessels or the allantoic duct.

Peritoneal cavity (cavum peritonei)

The peritoneum provides both the serosal lining of the peritoneal cavity, and also forms reflections, which extend from the body wall to surround the intraperitoneal organs. The peritoneum can therefore be divided into a **parietal part,** lining the walls of the abdominal cavity, a **visceral part,** directly surrounding the organs and a series of **double folds** connecting the parietal to the visceral parts. These folds, generally called **mesenteries** convey blood vessels, nerves and lymphatics. They also contain lymph nodes and fat (for a more detailed description of the mesenteries, see specific organ systems). At surgery the mesentery can be useful as an aid for orientation and for identification of certain organs.

The **peritoneal cavity** communicates with the pleural cavity through three openings in the diaphragm (Fig. 2-14):

- **Aortic hiatus** (hiatus aorticus), between the left and right diaphragmatic crus ventral to the lumbar vertebrae, through which the aorta, the azygos vein and the thoracic duct passe,
- **Esophageal hiatus** (hiatus oesophageus), ventrally between the divisions of the right crus, through which the esophagus, the dorsal and ventral vagal trunks and their supplying blood vessels pass and
- **Caval foramen** (foramen venae cavae), within the central tendon, through which the caudal vena cava passes.

While the aortic and esophageal hiatus slide over the structures, which pass through them, the caudal vena cava is fused to the surrounding central tendon. The **thoracic duct** (ductus thoracicus), which passes through the aortic hiatus is the **major lymphatic duct,** draining the abdominal and pelvic cavities. It arises from the cisterna chyli between the two diaphragmatic crura. The left and right **sympathetic trunk** and the **major** and **minor splanchnic nerves** pass between the pleural and peritoneal cavities, dorsal to the diaphragmatic crura.

The peritoneal cavity is completely closed in the male, but in the female there is an opening at the abdominal end of each

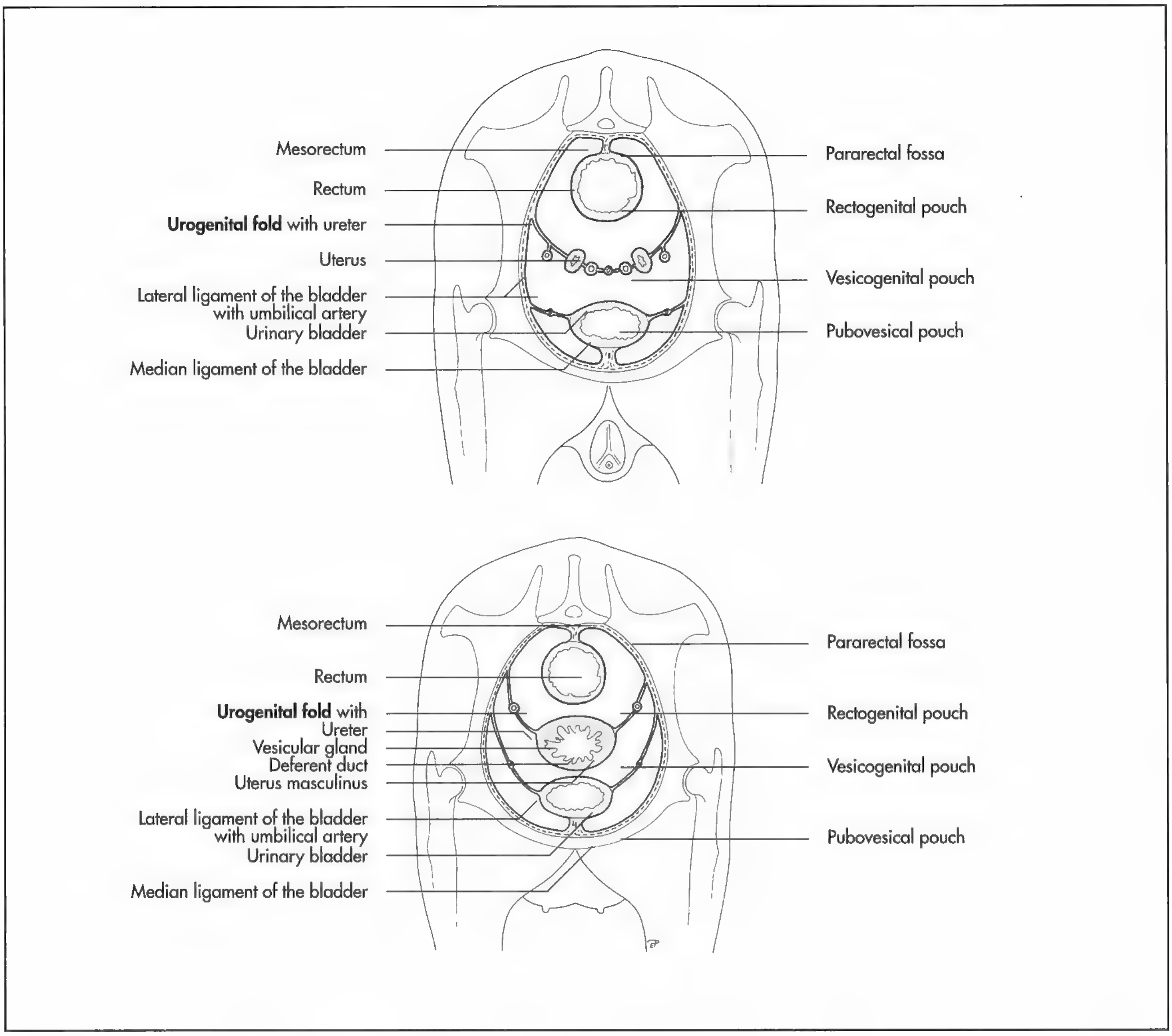

Fig. 6-22. Pelvic peritoneal excavations in the female (top) and male (bottom).

uterine tube and therefore there is a communication with the external genitalia and the peritoneal cavity. There are several pelvic peritoneal pouches:

- Vaginal process (processus vaginalis peritonei),
- Pubovesical pouch (excavatio pubovesicalis),
- Vesicogenital pouch (excavatio vesicogenitalis) and
- Rectogenital pouch (excavatio rectogenitalis).

In all male domestic animals and in the female dog, the peritoneum and the transverse fascia extend through the inguinal canal to line the **vaginal process** (processus vaginalis), into which the testis will be drawn during the process of testicular descent. In the bitch it contains the round ligament of uterus (ligamentum teres uteri), which corresponds to the gubernaculum testis in male animals.

Depending on their location organs can be grouped as:

- intraperitoneal,
- retroperitoneal and
- extraperitoneal.

Intraperitoneal structures include the gastrointestinal tract, with the exception of the caudal part of the rectum and the anus, the liver, the pancreas, the spleen and most of the urogenital tract, with the exception of the kidneys and parts of the ureters (Fig. 6-13, 6-14, 6-18 to 21).

During early embryonic development the gastrointestinal tract is attached along its whole length to the roof of the embryonic trunk by the **dorsal mesentery** (mesenterium dorsale) (Fig. 6-15). Only a short part of the foregut, which later forms the stomach and the proximal duodenum and a short

part of the distal hindgut have similar ventral attachments. As a consequence of the longitudinal growth of the gastrointestinal tract, the dorsal mesentery elongates, while at the same time the whole gastrointestinal tract rotates about 360° around the central **cranial mesenteric artery** (a. mesenterica cranialis) which becomes the cranial root of the **mesentery** (radix mesenterii) (Fig. 6-15). (For a more detailed description of this process see textbooks of embryology.)

In herbivores, the dorsal mesenteries are shorter, than in other species and are partly fused with the dorsal body wall, to support the large amounts of food within their gastrointestinal tract, whilst reducing pressure on the ventral body wall.

Pelvic cavity (cavum pelvis)

The pelvic cavity is encircled by the bony pelvis, which is formed by the sacrum, the first few caudal vertebrae and the pelvic bones, which meet ventrally in the pelvic symphysis. Grouped around this bony ring are the muscles of the hip and rump. The muscles of the pelvic girdle extend dorsally and laterally into the pelvic cavity. The terminal line marks the pelvic inlet. The pelvic outlet is bordered ventrally by the ischiatic arch, while the dorsal border differs between the species. Due to the mobility of the caudal vertebrae of carnivores, the pig and small ruminants the dimension of the pelvic outlet can be increased by moving the tail, which is important during parturition.

The rectum, anus (Fig. 6-13 and 6-14) and parts of the urinary bladder are located within the pelvic cavity. In females it also contains the uterine body, cervix, vagina and its vestibule and the urethra while in males it contains the pelvic part of the urethra, ductus deferens and the accessory sex glands.

The **cranial part of the pelvic cavity** is lined by peritoneum and is therefore referred to as the peritoneal part of the pelvic cavity. All organs in this part of the pelvic cavity are inflected in peritoneum: the urinary bladder has **two lateral ligaments** (ligamenta vesicae lateralia), which contain the remnants of the umbilical artery and the **central ligament** (ligamentum vesicae medianum), containing the urachus, which attaches the bladder ventrally. The uterus and the ovaries of the female genital tract are suspended by parts of the urogenital fold, which forms the broad **ligament of uterus** (ligamentum latum uteri).

At the border to the extraperitoneal part of the pelvis the peritoneum has several reflections forming the **pelvic peritoneal pouches** (excavationes) (Fig. 6-13 and 6-22):

- Pubovesical pouch (excavatio pubovesicalis),
- Vesicogenital pouch (excavatio vesicogenitalis) and
- Rectogenital pouch (excavatio rectogenitalis).

The **pubovesical pouch** is divided into two compartments by the central ligament of the urinary bladder. In males there is a communication between the rectogenital and the vesicogenital pouch. The pararectal fossae are the two dorsolateral extensions of the rectogenital pouch, next to the mesorectum. The caudal part of the pelvic cavity does not have a peritoneal lining and, is referred to as the retroperitoneal part. The outlet of the pelvic cavity is closed by the perineum. The principal component of the perineum being the pelvic diaphragm, an arrangement of the following muscles and their fascia:

- Paired coccygeal muscle,
- Paired levator ani muscle,
- External anal sphincter muscle (m. sphincter ani externus),
- Bulbospongious muscle (m. bulbospongiosus) and
- Urethral sphincter muscle (m. sphincter urethrae).

The **pelvic diaphragm** is perforated by the anus and the urogenital canal. The region between the ventral aspect of the root of the tail and the vulva or the scrotum is termed the perineal region. The, whereas the muscles and fascia, which interlace in a node between the vulva and the anus are referred to as the perineal body, however it is often termed “the perineum”.

7 Digestive system (apparatus digestorius)

H. E. König, J. Sautet and H.-G. Liebich

The digestive system is responsible for the break down of food into smaller portions, so that it can be utilised for energy, growth and cellular renewal. The organs belonging to this system are capable of receiving food, mechanically and chemically breaking it down into its constituent molecules and then absorbing them. Finally it has to eliminate unabsorbed and excreted residues. Cells of the digestive tract are important for this process and may possess hormonal functions. Nervous tissue, blood vessels and lymphatics all play an important role in digestion.

The digestive system consists of the alimentary canal, which extends from the mouth to the anus and also includes accessory glands: the salivary glands, the liver and the pancreas, which secrete digestive products into the alimentary canal.

The alimentary canal can be divided into five segments (Fig. 7-1):

- Mouth and pharynx
- Esophagus and stomach,
- Small intestine,
- Large intestine and
- Anal canal.

Mouth and pharynx

Oral cavity (cavum oris)

The main functions of the oral cavity are the procuring and mastication of food. Furthermore, saliva is secreted onto the ingested material for chemical digestion. The mouth (os) includes the lips, the oral cavity and its walls as well as the accessory structures that are located within (tongue and teeth) and those that drain into the oral cavity (salivary glands) (Fig. 7-2).

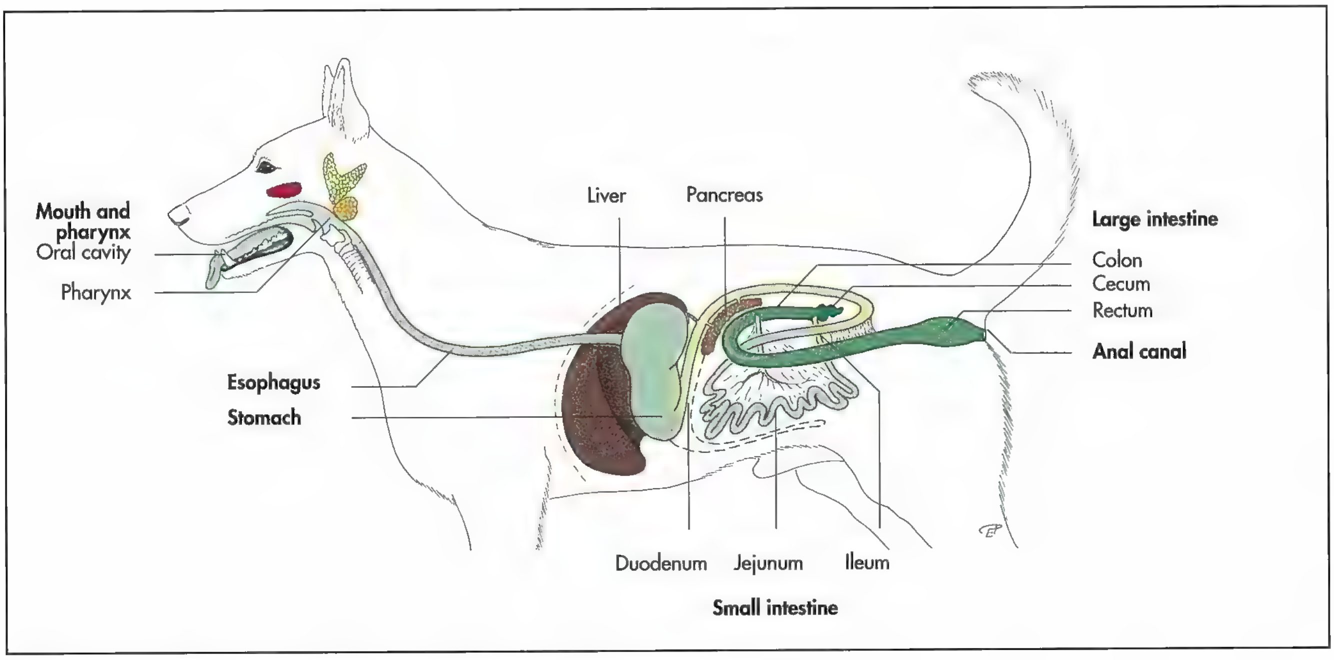

Fig 7-1. Gastrointestinal tract of the dog, schematic (Dyce, Sack and Wensing, 1991).

Fig 7-2. Sagittal section of the head of a horse.

The proportion of the mouth, which opens, varies between species, depending on feeding habits. Animals that use their teeth to capture prey, much of the mouth opens, while in herbivores and rodents a smaller orifice suffices.

The oral cavity is divided into the **vestibule** (vestibulum oris) and the **proper oral cavity** (cavum oris proprium). The proper oral cavity is the space within the dental arcades. It is bound by the palate dorsally, the tongue and reflected mucosa ventrally and by the teeth, dental arches and the gum laterally and rostrally (Fig. 7-2 and 7-13). The vestibule can be further subdivided into the **labial vestibule** (vestibulum labiale), the space between to the teeth and the lips and the **buccal vestibule** (vestibulum buccale) between the teeth and the cheeks (Fig. 7-3). The vestibule communicates with the proper oral cavity by means of the interdental spaces, the greatest of which being the **interalveolar margin** (diastema, margo interalveolaris) between the incisors and the cheek teeth.

The oral cavity has a mucosal lining, which consists of partly **cornified, stratified squamous epithelium.** Underlying which, is a layer of connective tissue, the submucosa, which contains **mixed glands.** Over the alveolar processes of the maxilla, mandibula and the incisive bone the mucosa is modified to form the **gums.** (For more details see histology textbooks.)

The **lips** (labia oris) frame the opening of the mouth and form the rostral and parts of the lateral borders of the vestibule. They are used for prehension of food, communication and suckling in new-born animals. They also contain tactile hairs in some species. The form of the lips is determined by diet and feeding habits. In the horse, the lips are used for collecting food and introducing it to the mouth; for this purpose the lips must be both sensitive and mobile. In the cat, where the teeth and tongue are more important for prehension, the lips are less mobile and much reduced in size. The lips of the dog can be drawn back from the teeth to signal aggression and form an important factor in communication, but are incapable of food intake. In the ox and the pig, the upper lip is modified to form the extensive moist and glandular **nasolabial plate** of the ox and the **rostral disc** of the pig. The insensitive lips of the ox, together with the backward orientated papillae on the palate and tongue are thought to be explain why the ox is prone to swallow foreign bodies. The upper lip is divided by a **median groove** (philtrum) in the dog and small ruminants.

The lips are composed of skin, an intermediate layer of muscles (orbicular muscle, incisive muscles and others) and the oral mucosa. The muscles that make up the greater part of the lips belong to the mimetic musculature; thus they are innervated by cranial nerve VII, the facial nerve.

The structure of the **cheeks** (buccae) is similar to that of the lips. They are formed primarily of the buccinator muscle, and contain additional **salivary glands** (glandulae buccales), which are aggregated in carnivores to form the **zygomatic salivary gland** (glandula zygomatica). A small papilla signifies the opening of the duct of the parotid gland within the lips. In ruminants, whose food may be coarse and dry, additional protection is provided by large, caudally directed, pointed papillae (Fig. 7-9).

Palate (palatum)

The palate is a partly osseous, partly soft tissue partition that separates the digestive and respiratory passages of the head. The bony hard palate lies rostral to the the membranous soft palate. The **hard palate** (palatum durum) is formed by the

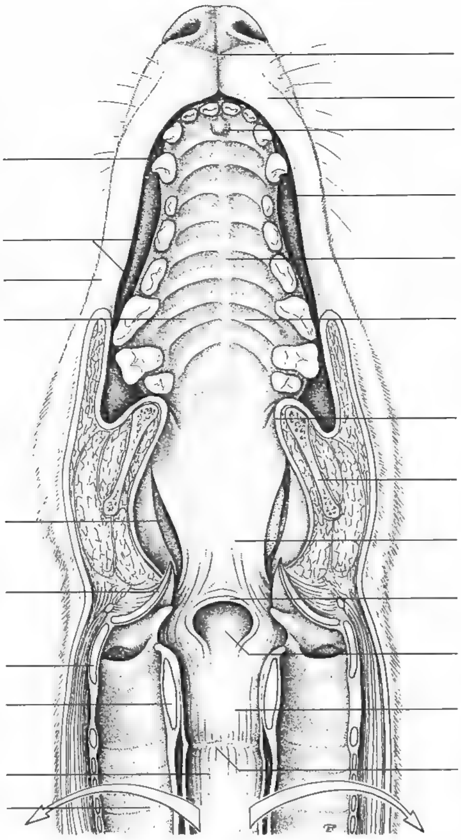

Fig 7-3. Frontal section through the oral cavity and pharynx of the dog, ventral aspect (Dyce, Sack and Wensing, 1991).

palatine processes of the maxilla and incisive bones and the horizontal plate of the palatine bone. The oral side of the hard palate is covered by a thick, cornified mucosa, which is crossed by a **series of transverse ridges** (rugae palatinae). In ruminants these ridges carry **papillae,** which are directed caudally to guide food backwards (Fig. 7-6). A small median swelling, the incisive papilla, is located just caudal to the incisors and is flanked on each side by the orifices of the incisive ducts, which perforate the palate. These ducts branch out and lead to the nasal cavity and to the vomeronasal organ, which is a blind-ending canal, lined by olfactory mucosa. In the horse the incisive ducts do not connect the nasal with the oral cavity, but are blind-ending. In ruminants the dental pad replaces the upper incisors of the other domestic species (Fig. 7-6). The pad acts as a counterpart for the lower incisors during food intake.

A dense, richly vascularised tissue underlying the palatine epithelium functions both as the lamina propria of the mucosa and as the periostium of the bone, thus forming a very tight attachment. Peripherally the mucosa of the hard palate blends with the mucosa of the gums. The gums are composed of dense fibrous tissue and the heavily vascularised mucosa. It extends around the necks of the teeth and down into the alveoli, where it is continuous with the alveolar periostium.

The **soft palate** (palatum molle or velum palatinum) continues caudally from the hard palate to the intrapharyngeal opening, the rostral border of which is formed by the caudal rim of the soft palate (arcus palatopharyngeus) (Fig. 7-3). The ventral surface of the soft palate is covered by oral mucosa, which forms many longitudinal and a few larger transverse folds. The dorsal surface is covered by respiratory mucosa. The intermediate layer consists of closely packed salivary glands and muscles and their aponeuroses. These muscles are responsible for active movement of the soft palate: the palatinus muscle shortens the palate, the tensor muscle tenses and the levator raises the soft palate. The mucous membranes of the pharynx, as well as the soft palate and the muscles, with the exception of the tensor muscle of the soft palate, are innervated by a plexus formed mainly by the vagus nerve, and to a lesser extent by the glossopharyngeal nerve. The tensor muscle of the soft palate is innervated by the mandibular nerve.

Tongue (lingua, glossa)

The tongue is composed primarily of skeletal muscle. It occupies the greater part of the oral cavity proper and extends into the oropharynx. The tongue is responsible for lapping water, prehension of food, manipulating the food within the

Fig 7-4. Tongue and pharynx of a dog, dorsal aspect.

Fig 7-5. Tongue and pharynx of a cat, dorsal aspect (König, 1992).

Fig 7-6. Roof of the oral cavity of an ox.

mouth and swallowing. It possesses receptors for taste, temperature and pain. In the dog it is used to enhance heat loss by panting, facilitated by the generous blood supply and numerous arteriovenous anastomoses together with dead-space (larynx, trachea and mainstem bronchi) ventilation.

The tongue has an **apex** (apex linguae), **body** (corpus linguae) and **root** (radix linguae). The body of the tongue is joined to the oral floor by a mucosal fold, the **frenulum** (frenulum linguae). The dorsal aspect of the canine tongue is marked longitudinally by a **median groove** (sulcus medianus) from which a septum extends into the tongue (Fig. 7-4). In carnivores the ventral part of the tongue contains a rod-shaped fibrous body, the **lyssa,** which lies in the median plane, beneath the ventral mucosa. It extends from almost the tip of the tongue to root of the tongue, but does not reach the hyoid bone. It is encapsulated in a dense sheath of connective tissue, which is filled with adipose tissue, striated muscle and, occasionally, islands of cartilage.

In cattle, the caudal part of the **dorsal surface of the tongue** (dorsum linguae) is raised to form a large prominence, that is defined by the transverse lingual fossa, in which food has a tendancy to collect. This is a potential portal for infection since the epithelium within the fossa is easily damaged by sharp food particles (Fig. 7-7). The tongue of the horse is strengthened by cartilage (cartilago dorsi linguae) within the dorsal part of the tongue (Fig. 7-7).

The **lingual mucosa** is tough and tightly adherent to the underlying musclularis on the dorsal and lateral aspect, but looser and less heavily keratinised ventrally. Much of the surface is covered by a variety of papillae, which are local modifications of the lingual mucosa. Their distribution, size, number and form are characteristic for each species. Based on their function they are grouped into **mechanic papillae** (papillae mechanicae), which are cornified and aid in licking while protecting the deeper structures from injury. The

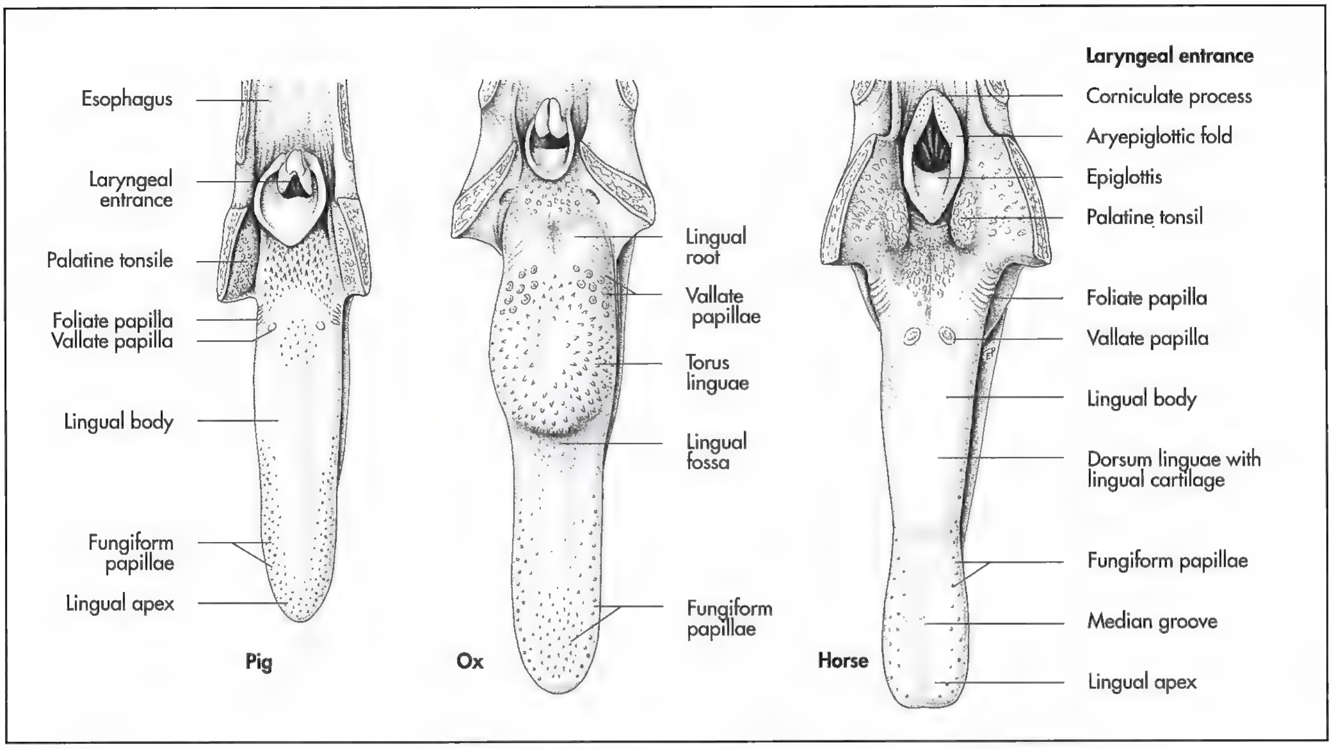

Fig 7-7. Tongue, pharynx and esophagus (sectioned in the median plane) of pig, ox and horse, dorsal aspect, schematic.

gustatory papillae are covered in **taste buds** (papillae gustatoriae).

- **Mechanical papillae** (papillae mechanicae):
  - Filiform papillae (papillae filiformes),
  - Conical papillae (papillae conicae),
  - Marginal papillae (papillae marginales).

- **Gustatory papillae** (papillae gustatoriae):
  - Fungiform papillae (papillae fungiformes),
  - Vallate papillae (papillae vallatae),
  - Foliate papillae (papillae foliatae).

Mechanical papillae are more numerous than the gustatory papillae. The **filiform papillae** are the smallest and most numerous of all papillae. The **conical papillae** are bigger in size, but less frequent. They are scattered widely over the dorsal surface of the feline tongue and the base of the tongue in the ox, which accounts for the rasp-like surface typical of these species. **Marginal papillae** are present in new-born carnivores and piglets and aids suckling.

The epithelium of the gustatory papillae contains **taste buds,** which are sensitive to taste. Their names indicate shape: fungiform, vallate and foliate papillae. A few salivary glands are situated in close proximity to these papillae. These glands remove food particles from the papillae, making them available for new food material entering the mouth. A more detailed description of the lingual papillae can be found in histology texts.

The extensive mobility of the tongue, making it capable of complex, precise movements, is achieved by a very special muscular architecture. The **musculature of the tongue** (mm. linguae) is divided into intrinsic and extrinsic groups.

The **intrinsic muscle of the tongue** (m. lingualis proprius) is composed of numerous bundles, that run longitudinally, transversely and vertically without attaching to the hyoid apperatus (Fig. 7-13). They are classified according to their orientation:

- Superficial and deep longitudinal fibers (fibrae longitudinales superficiales et profundae),
- Transverse fibers (fibrae transversae),
- Perpendicular fibers (fibrae perpendiculares).

There are three pairs of extrinsic muscles, which have an osseous origin and radiate into the tongue (Fig. 7-13). The first part of the name indicates the bone they originate from. They are arranged parallel to each other from lateral to medial in the following order:

- Styloglossal muscle (m. styloglossus),
- Hyoglossal muscle (m. hyoglossus),
- Genioglossal muscle (m. genioglossus).

The **mylohyoid muscle** (m. mylohyoideus) suspends the tongue between the mandibular bodies and is important for the induction of deglutition. Some textbooks include the geniohyoid muscle in this group of muscles, since it moves the hyoid bone and thus the tongue rostrally (Fig. 7-13).

The **vascular supply** to the tongue is primarily through the paired lingual artery, complemented by the paired sublingual

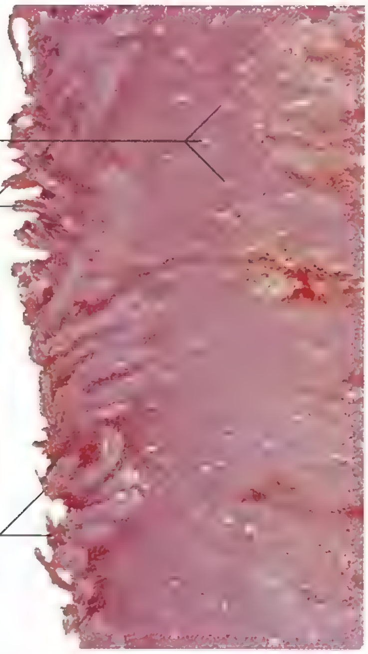

Fig 7-8. Papillae on the dorsal surface of the tongue in a piglet.

Fig 7-9. Conical papillae of an ox as an example for mechanical papillae.

Fig 7-10. Papillae at the base of the tongue in an ox.

Fig 7-11. Section of the tongue of a goat, centered on a vallate papillae.

artery, both of which arise from the linguofacial trunk. They extend numerous branches towards the dorsal surface of the tongue, which subdivide into several smaller branches within the mucosa. The sublingual vein is of practical importance, since it is easily visible on the ventral side of the tongue, and can be used for venipuncture in the clinical setting.

The **innervation** of the tongue is complex, involving five of the cranial nerves:

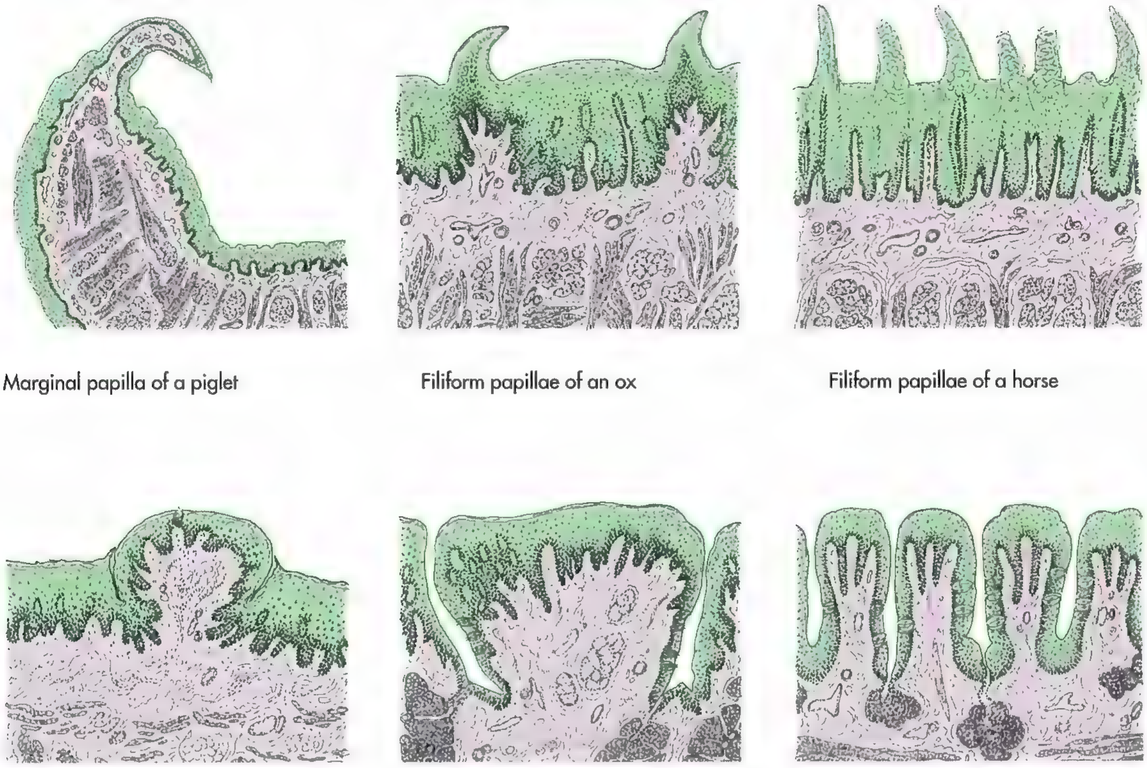

Fig 7-12. Lingual papillae, schematic (Liebich, 2004).

- The lingual branch of the mandibular nerve (of the trigeminal nerve),
- The chorda tympani of the intermediofacial nerve,
- Glossopharyngeal nerve,
- Vagal nerve and
- Hypoglossal nerve.

The **lingual nerve,** a branch of the trigeminal nerve provides tactile, pain and thermal innervation from the rostral two-thirds of the tongue. The **chorda tympani,** a branch of the facial nerve supplies mechanincal and chemoreceptor fibre innervation to the whole tongue as well as some taste fibers. The **parasympathetic fibres** of the latter form synapses in the **mandibular ganglion.** The caudal third of the tongue is innervated by the lingual branch of the **glossopharyngeal nerve** supplying taste fibres for this area. The root of the tongue receives additional innervation from branches of the **vagal nerve.** The **hypoglossal nerve** contains the general somatic motor fibers, which innervate the musculature of the tongue. Damage of this nerve results in **paralysis of the tongue.** This clinical sign is seen after trauma to the head or as a complication after **guttural pouch disease** in the horse.

Sublingual floor of the oral cavity

With the exception of the attachment of the tongue, the sublingual area is relatively featureless. The largest area extends rostral to the frenulum, behind the incisor teeth and is called the **prefrenular part** of the sublingual floor. The **two sublingual recesses** (recessus sublinguales laterales) extend between the tongue and the mandible on each side. Just in front of the frenulum lie two protuberances, the **sublingual caruncles** (carunculae sublinguales). These carry the common openings of the mandibular duct, which drains the mandibular salivary gland and the major sublingual salivary duct, which drains the major sublingual salivary gland. The latter is not present in the horse. The caruncles are relatively large in ruminants, well-developed in the horse, small in carnivores and sometimes absent in the pig. They are especially expansive in cattle, where they have a characteristically serrated border. In the horse and goat there may be a small gland adjacent to the **caruncles** (glandula paracaruncularis).

Lymhphoreticular tissue can be found in all species in this area. Just caudal to the incisors are the paired orobasal organs, which are thought to be the remnants of the rostral sublingual gland, which are still present in reptiles.

The lateral sublingual recesses are marked by a longitudinal fold (plica sublingualis), which carries the openings of the **mi-**

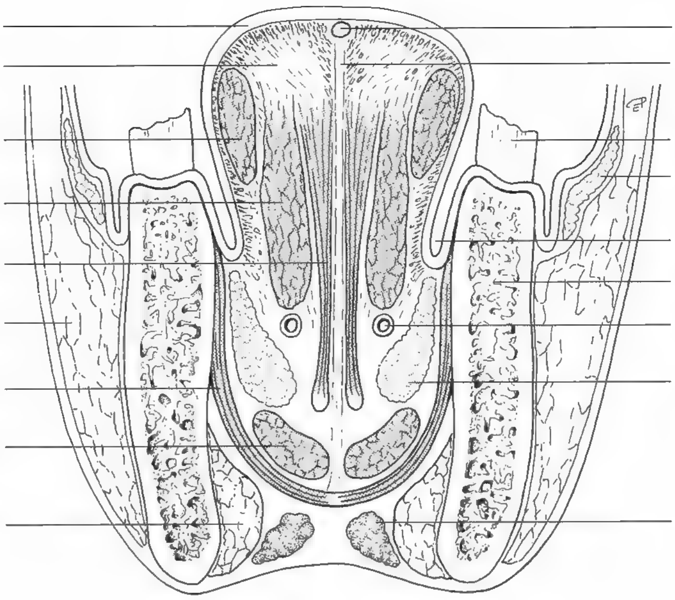

Fig 7-13. Sublingual floor of the oral cavity and tongue of the horse, transverse section, schematic.

nor sublingual salivary gland (glandula sublingualis minoris seu polystomatica). In cattle these openings are found on top of a series of conical papillae, whereas in the horse the minor sublingual salivary gland protrudes visibly.

Salivary glands (glandulae salivariae)

The salivary glands are paired organs that secrete saliva, via their ducts into the oral cavity. Saliva keeps the mucosa of the mouth moist and is mixed with the food during mastication to lubricate the passage of the food bolus during swallowing and initate chemical digestion of food.

The salivary glands are grouped into:

- Minor salivary glands (gll. salivariae minores),
- Major salivary glands (gll. salivariae majores).

Small or **minor salivary glands** are present in the mucosa of the lips, cheeks, tongue, palate and the sublingual oral floor. These glands produce a **mucous secretion.** The buccal minor salivary glands form larger aggregates ventrally and dorsally. In canines the latter is referred to as **zygomatic gland,** based on its position. Ruminants have an additional middle group of buccal glands.

The majority of saliva is produced by the **major salivary glands.** These are located at a distance from the oral cavity and drain through ducts. These glands produce a more **watery (serous) fluid,** some of them a serous-mucous secretion containing the enzyme **amylase** which initiates carbohydrate digestion. Saliva consists principally of water, as well as mucin, amylase and salts especially sodium bicarbonate. The daily production of saliva in the horse is about 40 l, in the ox 110–180 l, in the pig 15 l.

Although the flow of saliva is normally continuous, its rate of secretion is controlled by **sympathetic** and **parasympathetic innervation.** Parasympathetic innervation is provided by the cranial nerves V, VII and IX and is brought about by olfaction and taste, leading to an increase in saliva secretion and dilatation of blood vessels. The sympathetic fibres originate from the caudal thoracic segments of the spinal cord, form synapses in the cranial cervical ganglion and reach the salivary glands in the tunica adventitia of the arteries. Stimulation is followed by vasoconstriction, which slows the rate of production. Anxiety, stress or fear leads to a depression of saliva production, but also dehydration, which leads to the sensation of thirst. Pavlov has shown in his experiments, that flow rate of saliva can be increased by conditioning the animal to react to other stimuli, such as a bell.

In addition to its cleansing, lubricant and digestive functions, saliva serves as a route for excretion of certain substances, some of which may accumulate as a deposit (tartar) on the teeth, especially in dogs and cats. The major salivary glands are:

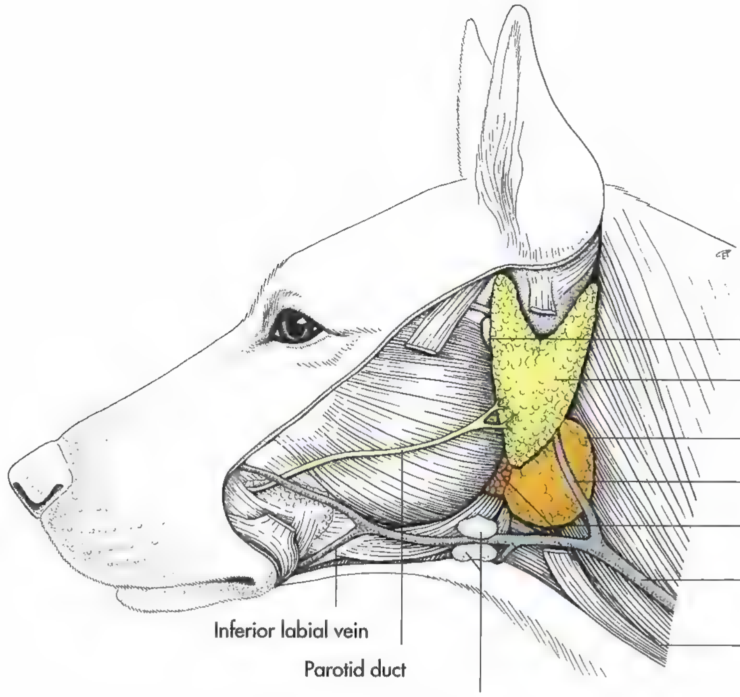

Fig 7-14. Topography of the salivary glands of the dog.

- Parotid salivary gland (glandula parotis),
- Mandibular salivary gland (gl. mandibularis),
- Sublingual salivary glands (gll. sublinguales),
  - Monostomatic sublingual salivary gland (gl. sublingualis monostomatica) and
  - Polystomatic sublingual salivary gland (gl. sublingualis polystomatica).

Parotid salivary gland (glandula parotis)

The parotid salivary gland is a paired organ, which lies at the junction of the head and neck, ventral to the **auricular cartilage in the retromandibular fossa** (Fig. 7-14 to 16). It is especially well-developed in herbivores. The parotid salivary gland is a **mixed, serous-mucous, tubuloacinous type gland.** It is in close proximity to the external carotid artery, the maxillary vein and branches of the facial and trigeminal nerves. In the horse it partially overlays the lateral wall of the **guttural pouch,** which must be taken into consideration, when using an external surgical approach to the guttural pouch.

The parotid salivary gland is enclosed within a facial covering that projects trabeculae inwards to divide the gland into **several lobules.** The **major collecting ducts** pass within these trabeculae to eventually join forming a single duct that at the rostral aspect of the gland. In carnivores and small ruminants this duct passes over the **lateral surface of the masseter muscle.** In the horse, ox and pig it passes medial to the angle of the jaw rostrally and winds around the ventral margin of the mandible to emerge at the **rostral border of the masseter muscle.** In the horse it lies here just caudal to the linguofacial artery. The parotid duct opens into the oral vestibule at the top of a small papilla opposite the third to fifth cheek tooth depending on the species.

The parotid gland is vascularised by branches of the maxillary artery and vein. It is innervated by branches of the glossopharyngeal nerve, the parasympathetic fibers of which run with the minor petrosal nerve to the otic ganglion.

Mandibular salivary gland (glandula mandibularis)

The mandibular salivary gland is located close to the **angle of the jaw** and is partially covered by the parotid salivary gland (Fig. 7-14 to 16). It is slightly bigger than the parotid salivary gland in most dogs and cats, but considerably larger in ruminants. In carnivores it is oval in shape, situated subcutaneously, caudal to the monostomatic salivary gland between the linguofacial and maxillary veins. Both, the mandibular and the monostomatic salivary glands are of practical importance in the dog, since they can undergo **cystic changes** (ranula) which require their removal.

The mandibular salivary gland produces a **mixed mucous** and **serous secretion,** but can also alternate between the two.

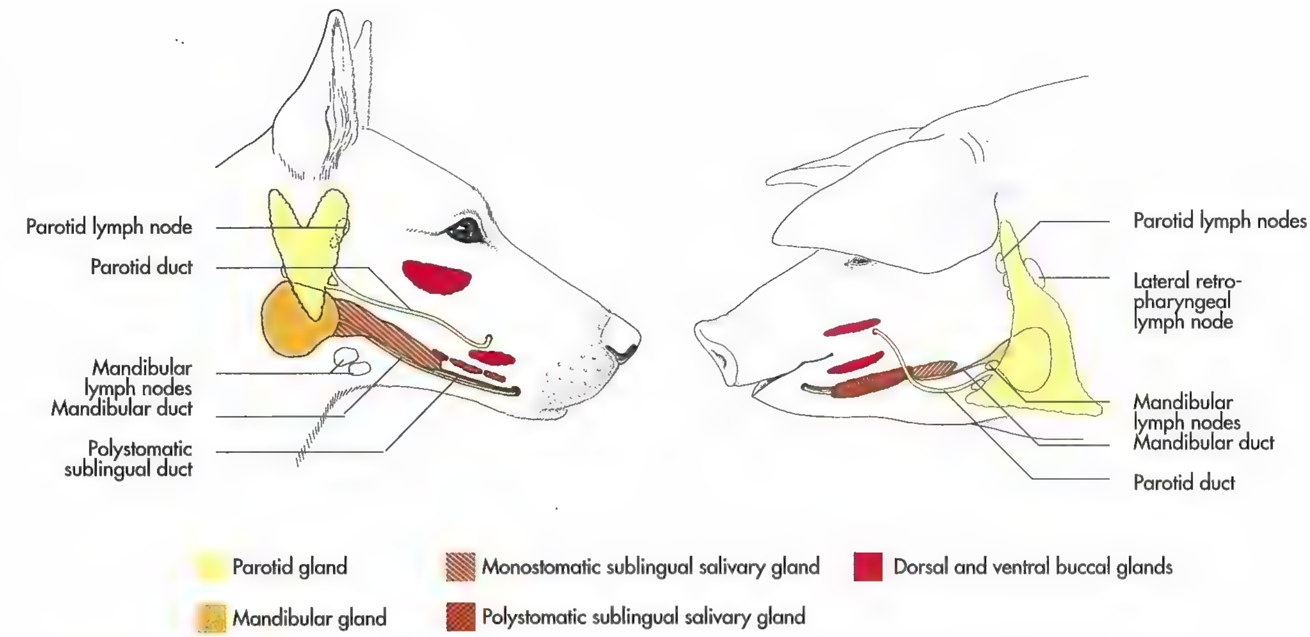

Fig 7-15. Salivary glands of the dog (left) and the pig (right), schematic (Dyce, Sack and Wensing, 1991).

It drains by a single large duct, which passes ventral to the mucosa of the **floor of the oral cavity,** close to the lingual frenulum to open with the major sublingual duct on the **sublingual caruncle.** The linguofacial artery and vein provide vascular supply to the mandibular salivary gland. Parasympathetic innervation is provided by fibres arising from the facial nerve. These fibers first run in the chorda tympani to the mandibular branch of the trigeminal nerve and continue in the lingual branch of the latter to the mandibular ganglion, where they synapse with postganglionic neurones.

Sublingual salivary glands (glandulae sublinguales)

The sublingual salivary glands consists of two glands on either side except the horse, in which the major (monostomatic) sublingual salivary gland is absent (Fig. 7-14). The **major (monostomatic) salivary gland** is situated more caudally and is a compact gland with a single draining duct. The major sublingual salivary duct shares a common opening with the mandibular salivary duct on top of the sublingual caruncle protruding from the prefrenular part of the floor of the oral cavity.

The diffuse **minor (polystomatic) salivary gland** is located more rostrally and opens through several smaller ducts. These openings are located on a longitudinal fold in the lateral sublingual recesses, in cattle on top of the conical papillae located on the fold.

Both sublingual salivary glands produce a serous-mucoid secretion in which the mucous part dominates. Blood supply and venous drainage is achieved by the lingual artery and vein. Innervation is similar to that of the mandibular salivary gland.

Masticatory apparatus

The masticatory apparatus includes:

- the teeth and gums,
- the temporomandibular joint,
- the masticatory muscles.

Teeth (dentes)

Each species has its own characteristic dentition, describing form and number of teeth. The teeth develop differently in each region of the mouth according to their use and are grouped into **incisors, canines, premolars** and **molars.** This characteristic feature is termed **heterodonty** (derived form greek “heteros”, meaning different). The dentition of the domestic mammals is **diphyodont,** in that the first erupted teeth are replaced by a single set of teeth in older animals. The first set of the teeth, the **deciduous teeth** (dentes decidues), is either present at birth or erupt shortly afterwards. These teeth are replaced by the second replacement teeth, to adapt to the larger jaws and provide more vigorous mastication of the adult animal. The timing of replacement of the teeth is characteristic of each species. Other vertebrates have a **polyphyodont dentition (multiple successions)** whereby multiple sets of teeth erupt throughout the animals life.

Structure of the teeth

Although all teeth are highly specialised structures, modified according to the special needs of each species, they share a

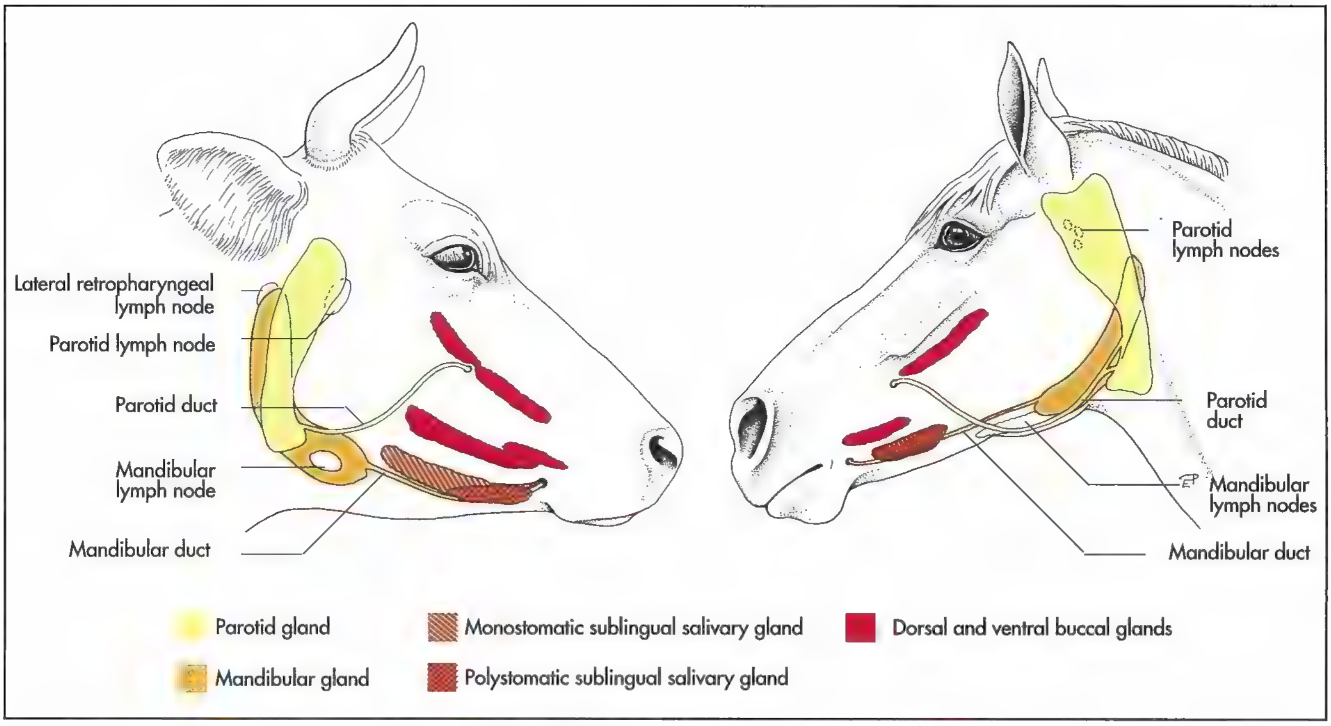

Fig 7-16. Salivary glands of the ox (left) and the horse (right), schematic (Dyce, Sack and Wensing, 1991).

common, basic architecture (Fig. 7-17 to 19). Each tooth is divided into three parts:

- Crown (corona dentis),
- Neck (collum dentis),
- Root (radix dentis).

The **crown** is the exposed part of the tooth, which protrudes above the gums and is covered by **enamel.** The **neck** is the slight constriction located at the gum line, where the enamel ends. The **root** is the portion below the gum, which is embedded in the bony alveolus for the most part. Each surface of the teeth is denoted by an unambiguous descriptive term which is especially important under clinical circumstances. The surfaces of the tooth that are directed towards the vestibule of the mouth are the **vestibular surfaces,** which can be indicated more precisely with the terms labial meaning towards the lips and buccal meaning towards the cheeks. The surface that is adjacent to the tongue is the **lingual surface.**

The **contact surface** (facies contactus) adjacent to the next rostral tooth in the dental arch is referred to as mesial surface and the surface adjacent to the next caudal tooth as distal. The surface that which contacts the adjacent arcade is termed the **masticatory** or **occlusal surface** (facies occlusalis).

Each tooth is composed of three different mineralised tissues, which enclose the **dental cavity** (cavum dentis). The dental cavity branches into each major elevation of the crown and into each root. It is filled with the **pulp** (pulpa dentis), which is composed of connective tissue, nerves, arteries and veins. A small **apical foramen** opens at the end of each root and allows free passage of the vessels and nerves in and out of the tooth through the **root canal** (canalis radicis dentis) (Fig. 7-19). Most of the nerves within the pulp are **sensory** and possess nerve endings, that can be stimulated in various ways resulting in pain sensation. As the pulp is surrounded by non-expansive tissue, even slight inflammatory can elicit pain responses.

The three mineralised substances of the tooth are:

- Enamel (enamelum),
- Dentin (dentinum),
- Cement (cementum).

Their chemical composition is similar to that of bone, being composed mainly of hydroxylapatite. **Enamel** is produced by **adamantoblasts,** which are of ectodermal origin. It is acellular and therefore cannot regenerate. It has a typical slightly opalescent, pearly-white colour and is the hardest substance in the body (Fig. 7-20). Based on the distribution of enamel, teeth can be divided into **brachyodont type teeth** and **hypselodont teeth.** In the relatively simple, brachyodont teeth (e.g. teeth of man, dog, pig, canines of all domestic mammals) enamel envelops the short exposed crown. Brachyodont teeth erupt fully prior to maturity and are normally long and hard enough to survive for the life of the individual. Hypselodont teeth are high-crowned teeth, in which a large portion of the crown is initially held in reserve to be extruded gradually to compensate for attrition (e.g. the cheek teeth of herbivores, equine incisors).

For this reason, it is useful to distinguish between the clinical crown (exposed crown) and the anatomical crown (covered by enamel) as well as the clinical root (below gum line) and anatomical root (not covered by enamel and

Fig 7-17. Section of an equine incisor.

Fig 7-18. Section of an equine cheek tooth.

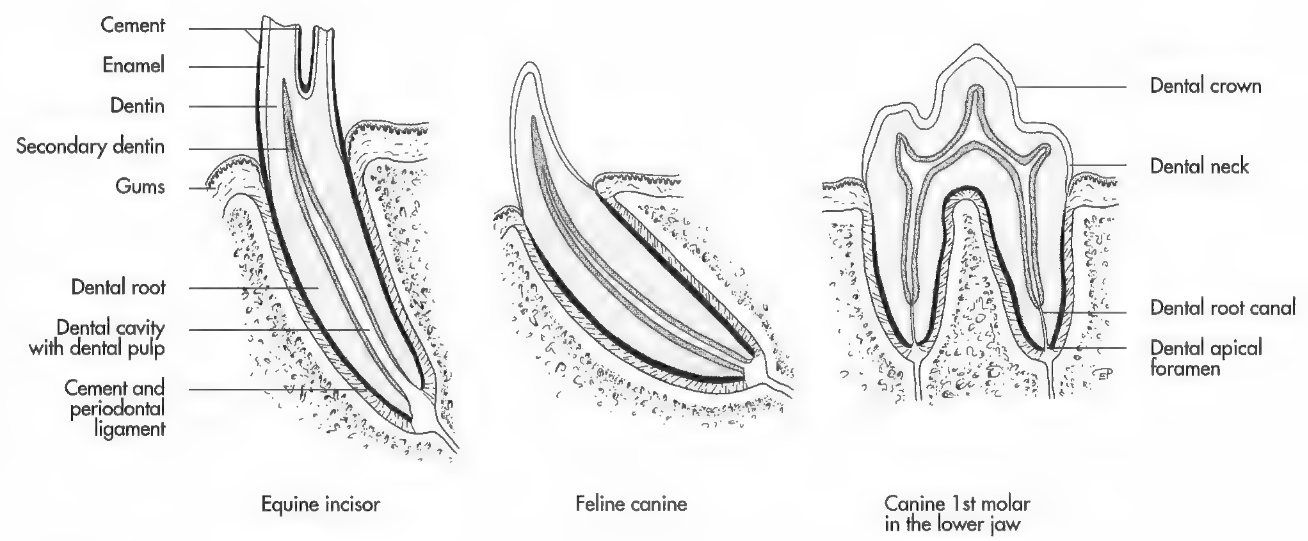

Fig 7-19. Hypselodont and brachyodont teeth, schematic.

in hypselodont teeth relatively short). Hypselodont teeth have a complex architecture, in which the mineralised layers of the tooth are arranged in **folds** and the whole of the crown, above and below the gum line is covered by **enamel.** This special architecture, where layers of the harder, but more brittle enamel come to lay next to the less hard, but more plastic **dentine** provides maximum resistance to the abrasive food of herbivores and provides a rasp-like occlusal surface. Both brachyodont and hypselodont teeth have a **limited growth period** and thus are termed **anelodont teeth.** Teeth that continue to grow throughout life are called **elodont teeth** and are found in some rodents.

Dentin forms the bulk of the tooth enclosing the **pulp cavity** and is yellowish-white in colour. (Fig. 7-20). It is

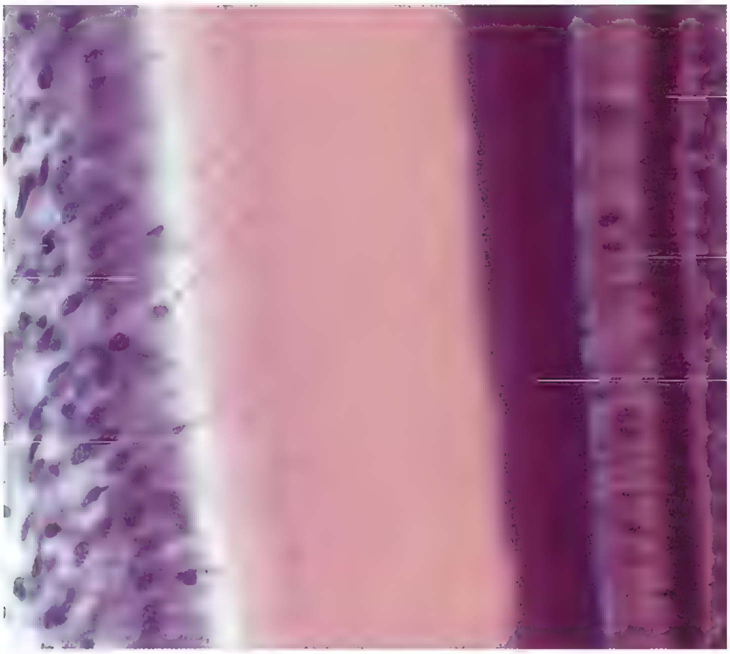

Fig 7-20. Section of the tooth wall.

produced by **odontoblasts,** which recede from the newly formed dentine to remain as a continuous layer lining the pulp cavity. The odontoblasts retain their productive capacity throughout life and slow production of secondary dentine, which gradually fills the pulp cavity, continues into old age. Secondary dentine can be distinguished from primary dentine by its darker colour. In horses, the time of appearance of the pulp cavity, filled with secondary dentine at the occlusal surface of the incisors **(dental star)** is used for ageing. In the dog the reduction of the pulp cavity by secondary dentine can be assessed radiographically and is also an indicator of age.

Cement is the least hard of the calcified tissues of the tooth and very similar to bone (Fig. 7-19). It is the outermost layer adjacent to the alveolar bone (alveolus dentalis) in all types of teeth and fills the infundibula of the hypselodont teeth. The tooth is attached to its alveolar socket by the **periodontal ligament** or **membrane** (periodontium). This contains collagen fibres which are continuous with both the cement and the bone. These fibers are orientated so that the tooth is suspended in a sling, thus enabling the tooth to withstand minute movements and the considerable forces generated during mastication. Although similar to bone in structure, **cement** is more resistant to erosion from pressure. This is of orthodontic use in cases, where a tooth is manipulated by instruments that lever the tooth against the alveolar wall. The resulting pressure causes erosion of the bone, but leaves the tooth itself unaffected. (A more detailed description can be found in orthodontic textbooks.)

The **gums** (gingivae) are composed of dense fibrous tissue, covered by a smooth heavily vascularised mucosa. They extend around the neck of the teeth, but may recede with advancing age, exposing the neck of the root.

The number and classification of dentition can be described by the **dental formula** of that species. The abbreviation representing the particular teeth (I=incisor, C=canine, P=premolar, M=molar) is followed by the number of such teeth on one side of the upper and lower arcade. A "d" behind the abbreviation indicates a deciduous tooth (e.g. Id 3 for the deciduous incisor 3).

Dental formulae

	Deciduous Dentition	Permanent Dentition
Horse	3 1 3	3 1 3 (4) 3
	3 1 3	3 1 3 3
Ruminant	– – 3	– – 3 3
	3 1 3	3 1 3 3
Pig	3 1 3	3 1 4 3
	3 1 3	3 1 4 3
Dog	3 1 3	3 1 4 2
	3 1 3	3 1 4 3
Cat	3 1 3	3 1 3 1
	3 1 2	3 1 2 1

Since the time of tooth eruption is characteristic and consistant in the different species, it can be used for ageing of individuals. Although individual factors must be taken into consideration and are dependent on breed, feeding habits and medical history of the individual animal.

Dentition of the horse

The dentition of the horse is well-adapted to its feeding habits and diet, which normally consists of continuous grazing of rough, poorly-digestible grass (Fig. 7-21 to 23). While the incisors are specialised for prehension and cutting of food, the equine premolars 2–4 and the three molars function as grinders for mastication. All teeth of the horse, with the exception of the canines and the first premolar, when present, are hypselodont teeth. The masticatory surface is increased by the folding of the enamel during development, which results in alternation of harder and softer mineralised tissues providing a rasp-like grinding surface. In the incisors and in the maxillary cheek teeth this folding results in the formation of cement-filled infundibula (Fig. 7-17, 18 and 24–31).

Horses have twelve incisors, six in each arcade (Fig. 7-21 to 23). There are central, middle and corner incisors in the horse. Deciduous incisors are whiter, have a distinct neck and contain wider and shallower infundibula than their permanent successors, which erupt on their lingual aspect. Permanent incisors are curved convexly on their labial aspect and taper uniformly from the occlusal surface towards their apex. With advancing age, spaces develop between the permanent incisors. The infundibula of the incisors are referred to as cups and are an important indicator of the age of the horse (see below).

The **deciduous canine teeth** are vestigial spiccule-like structures that do not erupt. Male horses normally have two maxillary and two mandibular permanent canine teeth, that erupt at around 5 years of age in the interdental space (Fig. 7-21, 23 to 29). They are **brachyodont teeth** and are pointed with a caudal facing curve. The upper canines are more caudally positioned than the lower, thus there is no occlusal contact between them. This is alleged to be the reason why canine teeth are prone to develop calculus. Canine teeth are usually absent or rudimentary in female horses, but do occur in some mares, with a higher incidence reported in some breeds.

An **adult equine** mouth normally contains 24 cheek teeth (premolars 2–4 and three molars) (Fig. 7-21 and 22). The premolars have deciduous predecessors, which have a distinct neck between the crown and the roots unlike their permanent successors. Latterly the deciduous premolars erupt into the oral cavity due to pressure from the underlying tooth. They are simultaneously resorbed at their apices until just a thin plate ("cap") on the temporary tooth remains (Fig. 7-22 and 23).

On **transverse section** equine cheek teeth are rectangular except the first and last which are triangular. The maxillary cheek teeth are wider and squarer compared to the more rectangular and narrower mandibular ones. At the time of eruption the permanent cheek teeth possess long crowns, most of which is unerupted reserve crown that remains embedded in the alveoli. Eruption of the reserve crown proceeds throughout life and normally the eruption rate corresponds with tooth wear (about 2–3 mm a year). At eruption hypselodont teeth have no true roots, but develop roots later. Fully developed upper cheek teeth have three roots (occasionally four) and the lower cheek teeth have two roots (except the last lower molar which has three).

The maxillary cheek teeth have two cement-filled infundibula each, which make those teeth prone to caries. Pressure between the first and caudal cheek teeth tightly compress the six cheek teeth together at their occlusal surface. This factor along with the continuous deposition of coronal cement within the alveolus only causes each row to act as single functional unit.

In normal horses the distance between the maxillary arcades is wider than that between the mandibular arcades, a condition known as anisognathia. Additionally the occlusal surface of the cheek teeth are not level in the buccolingual plane, but are angled at 10–15 degrees. This leads to the development of sharp enamel points at the lingual edge of the mandibular cheek teeth and at the buccal edge of the maxillary cheek teeth, which should be removed regularly by floating.

Ageing of the horse

The regularity of eruption, growth, attrition and other characteristic changes of the equine teeth allow ageing of a horse by its incisors. Eruption of teeth has been found to be the most reliable feature, whereas attrition-caused changes are more dependent on individual factors, such as feeding habits. Ageing is most exact in horses up to six years of age, when the mandibular incisors are used and becomes increasingly inaccurate with advancing age.

As a result of wear, the occlusal surface of incisors changes: the cup gets smaller and finally disappears, the dental star appears and changes from a line to a large round spot (Fig. 7-24 to 29). Attrition erodes the incisor tooth by 2 mm each year. Since the cups of the mandibular incisors are 6 mm deep, they disappear three years after the tooth has come into wear. The cups of the maxillary teeth are 12 mm, thus the cups disappear six years after the tooth has come into wear. After eruption it takes about six months for an incisor to come into wear. The following shows approximate eruption times and the time of disappearance of the cups:

	Eruption	Disappearance of cup
Id1	6 days	10 months
Id2	6 weeks	12 months
Id3	6 months	18–24 months
Mandibular I1	2.5 years	6 years
Mandibular I2	3.5 years	7 years
Mandibular I3	4.5 years	8 years
Maxillary I1	2.5 years	9 years
Maxillary I2	3.5 years	10 years
Maxillary I3	4.5 years	11 years

The initially oval occlusal surface (6–12 years) of the incisors becomes rounded (12–17), then triangular (18-24) and finally forms a longitudinal oval (24-30) (Fig. 7-24 to 29).

Additional, but not very reliable criteria are a "hook" on upper I3, which is present in 7–8 year old horses, but may reappear at 13 years and Galvayne's groove which forms on the labial surface of the same tooth:

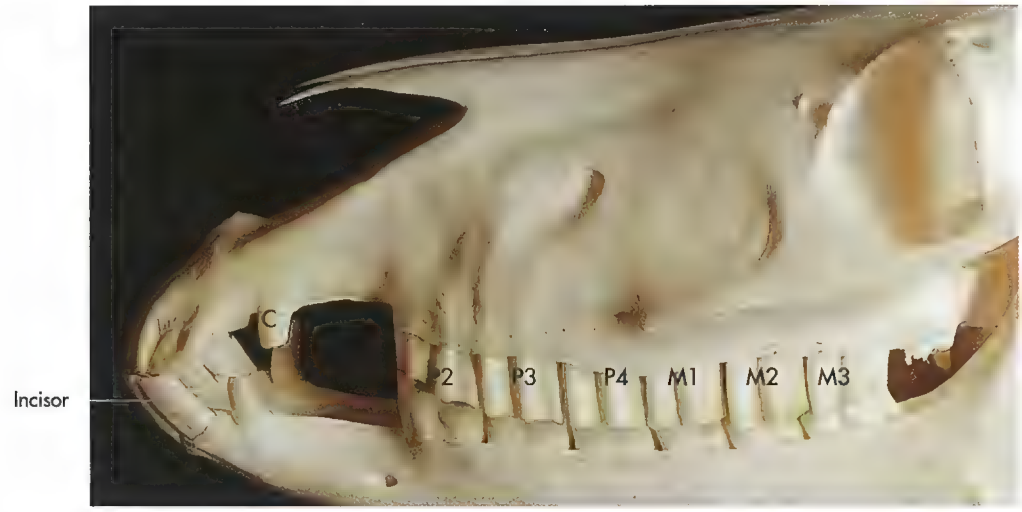

Fig 7-21. Permanent dentition of a stallion.

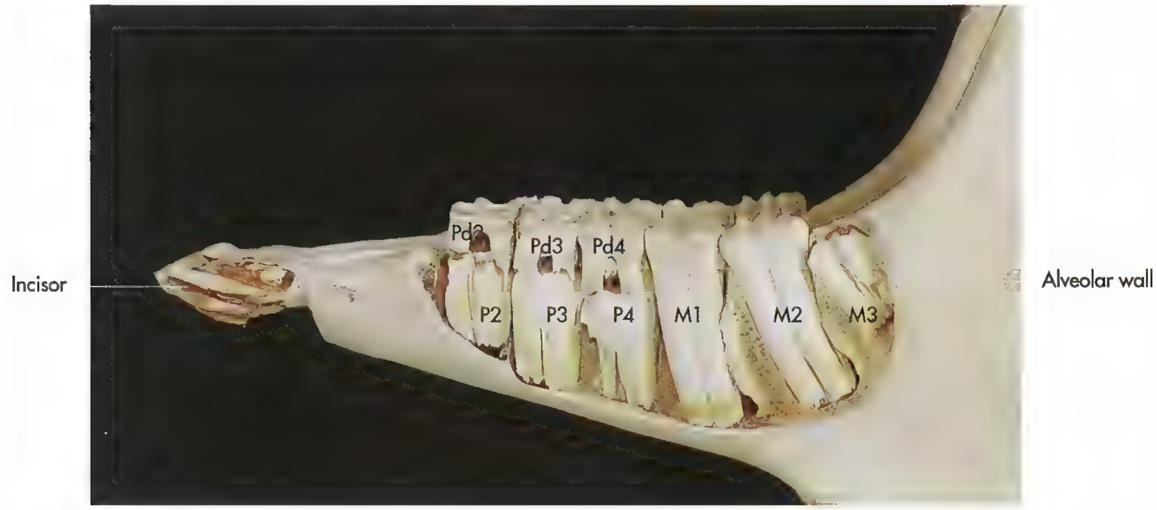

Fig 7-22. Mandibular arcade of a horse during eruption, tooth roots exposed.

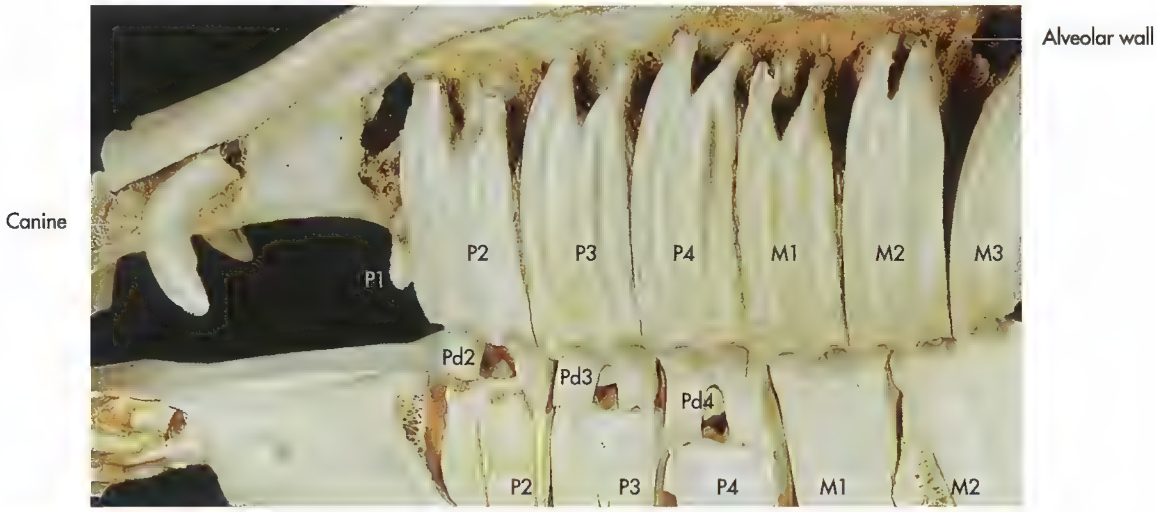

Fig 7-23. Mandibular and maxillary arcade during eruption, tooth roots exposed.

Fig 7-24. Occlusal surface of the mandibular incisors in a 3.5 year old horse, lingual aspect.

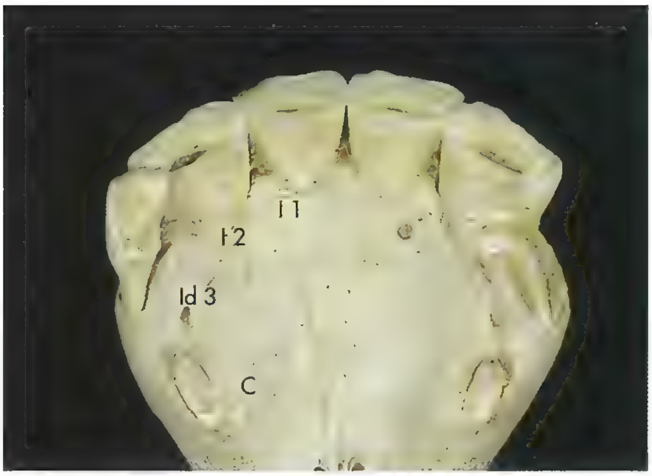

Fig 7-25. Occlusal surface of the mandibular incisors in a 4.5 year old horse, lingual aspect.

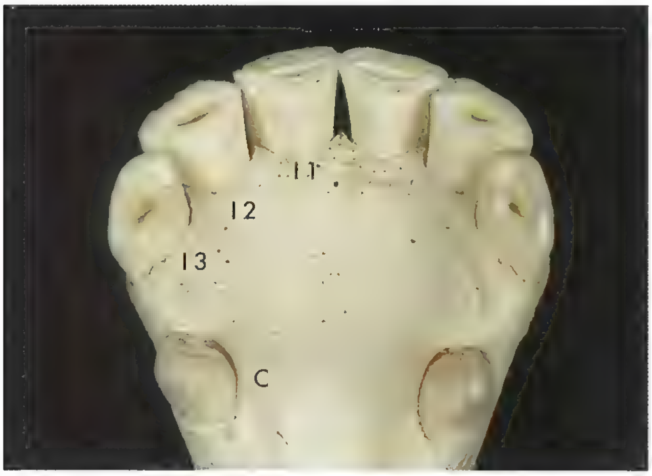

Fig 7-26. Occlusal surface of the mandibular incisors in a 6 year old horse, lingual aspect.

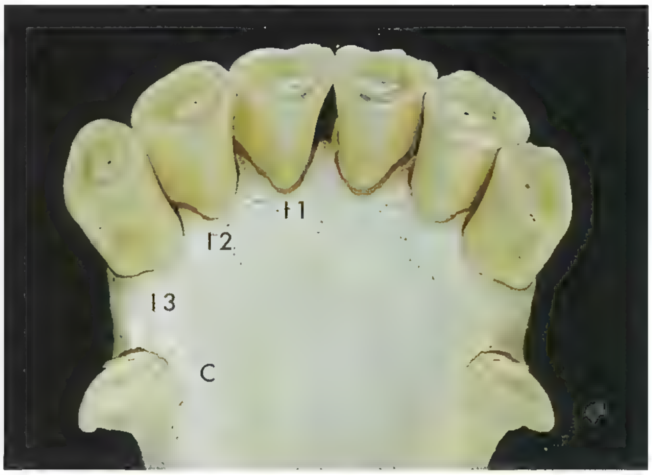

Fig 7-27. Occlusal surface of the mandibular incisors in a 10 year old horse, lingual aspect.

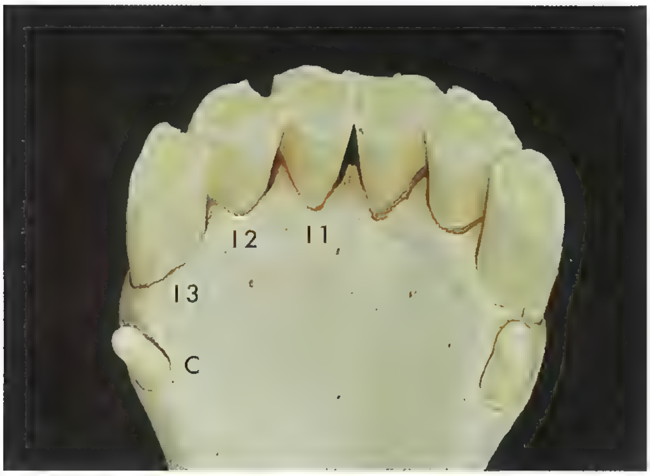

Fig 7-28. Occlusal surface of the mandibular incisors in a 12 year old horse, lingual aspect.

Fig 7-29. Occlusal surface of the mandibular incisors in a 17 year old horse, lingual aspect.

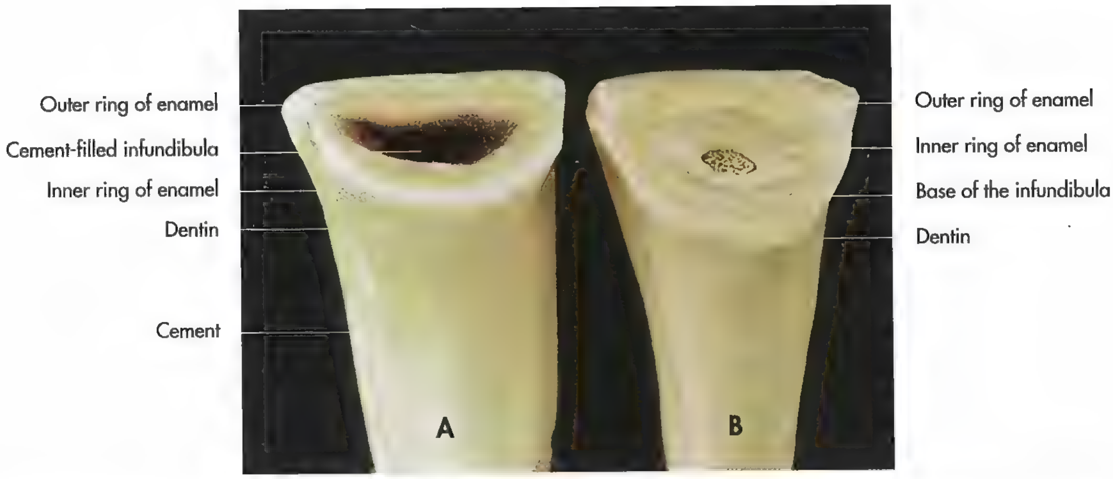

Fig 7-30. Occlusal surface of a younger horse **(A)** with a visible cup and of an older horse **(B)**, where the cup has disappeared, but the dental star is visible.

Abb. 7-31. Occlusal surface of a horse **(A)** and an ox **(B)**, (superior aspect).

- Dorsal third of maxillary I3: 10 years,
- Dorsal half of maxillary I3: 15 years,
- Whole length of maxillary I3: 20 years,
- Ventral half of maxillary I3: 25 years,
- Ventral third of maxillary I3: 30 years.

In horses with dental anomalies, such as brachygnathia or prognathia of the mandible or in horses with vices, such as crib biting, ageing by incisors is impossible. In those horses eruption times of cheek teeth and length of the reserve crown, assessed radiographically may be used as an indicator of age. Approximate eruption times of cheek teeth are:

P2 = 2.5 years, P3 = 3 years, P4 = 4 years,
M1 = 1year, M2 = 2years, M3 = 3.5years.

Dentition of the dog

The **small permanent incisors** are loosely embedded in their alveolar sockets and are mainly used for nibbling. The upper incisors present a central tubercle, flanked by two smaller ones. The lower incisors are similar to the upper ones, but lacking the mesial cusp. These features may be lost as wear reduces the incisors to simple prismatic pegs. This process is accelerated in dogs, which have the habit to bite into stones. The canines are by far the longest teeth of the dog, having large roots that are longer than their crowns (Fig. 7-34).

The **four premolars increase** in size and complexity from first to last in both jaws.

The **upper fourth premolars** are the largest cutting teeth of the maxilla. They are called **carnassial** or **sectorial teeth** and are sometimes referred to as shearing teeth. Each has three stout, diverging, conical roots. The upper fourth premolar is the tooth most commonly involved with root abscesses, which usually results in the formation of a discharging sinus tract

Fig 7-32. Dentition of a mountain lion, frontal aspect.

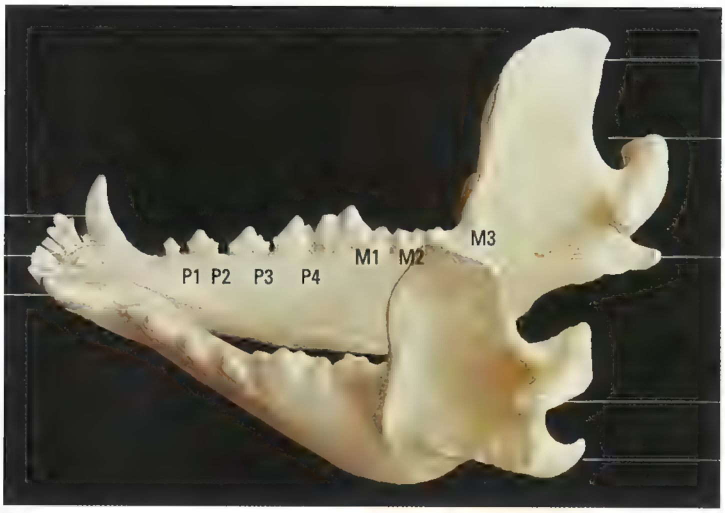

Fig 7-33. Mandibular teeth of a dog, caudolateral aspect.

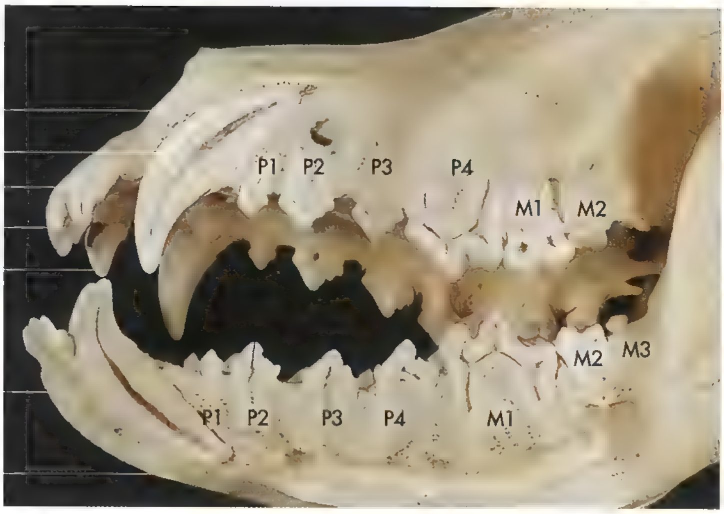

Fig 7-34. Sagittal section of the maxillary and mandibular teeth of a dog, lateral aspect.

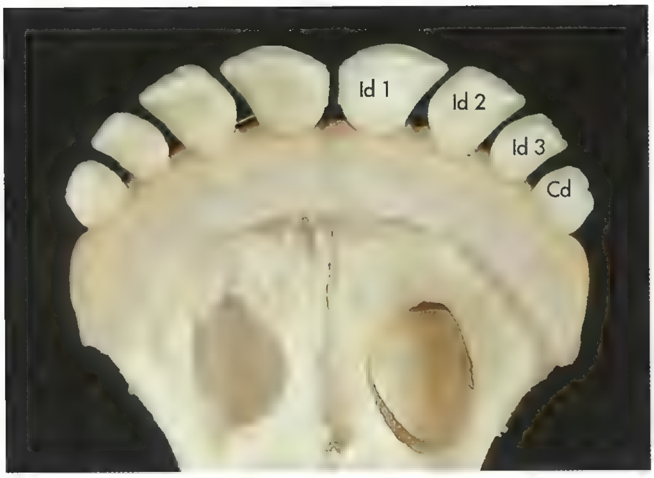

Fig 7-35. Occlusal surface of the deciduous mandibular incisors in a 1 year old ox, lingual aspect.

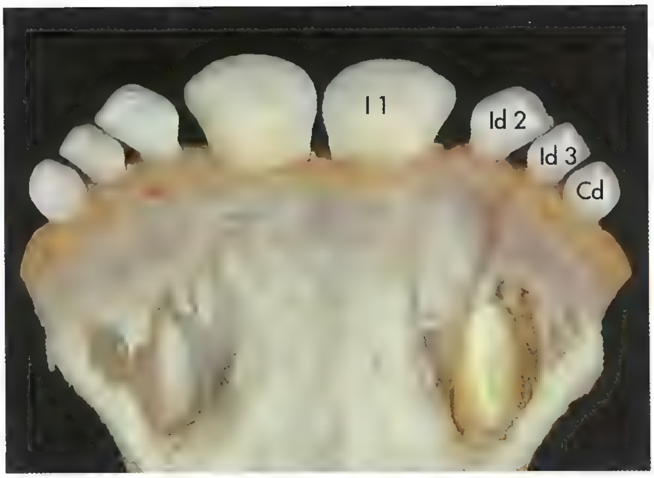

Fig 7-36. Occlusal surface of the mandibular incisors in a 1.5 year old ox, lingual aspect.

Fig 7-37. Occlusal surface of the mandibular incisors in a 2.5 year old ox, lingual aspect.

Fig 7-38. Occlusal surface of the mandibular incisors in a 3.5 year old ox, lingual aspect.

Fig 7-39. Occlusal surface of the mandibular incisors in a 4.5 year old ox, lingual aspect.

Fig 7-40. Occlusal surface of the mandibular incisors in a 5.5 year old ox, lingual aspect.

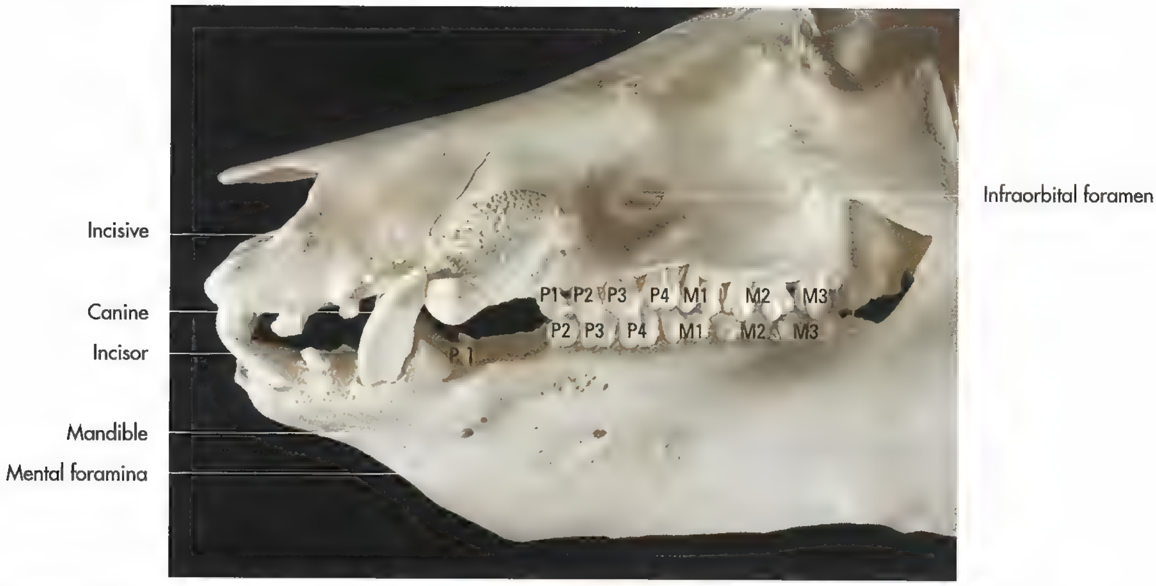

Fig 7-41. Dentition of a pig, lateral aspect.

rostroventral to the eye. Permanent cure requires extraction of the affected tooth. The molar teeth have no deciduous predecessors and decrease in size from first to last. The first of the lower molars is the largest tooth in the mandible. It is also called the sectorial or carnassial tooth of the mandibular arcade and very well-adapted to shearing action. It has two roots.

Eruption times of the canine teeth are: Deciduous incisors erupt between 4–6 weeks of age, deciduous canines 3–5 weeks and deciduous premolars 5–6 weeks of age, thus a complete first set of teeth is present in a 6 month old dog. Permanent incisors erupt between 3–5 months of age, the permanent canines at about 5–7 months and the cheeks teeth between 4–7 months of age. Ageing a dog by teeth is not reliable due to individual and breed variations in eruption times, diet and chewing habits.

Dentition of the cat

The domestic cat has only 30 teeth, due to the absence of P1, M2 and M3 in the upper jaw and P1, P2, M2 and M3 in the lower jaw (Fig. 7-32). Thus the cat lack the flat-crowned crushing teeth, leaving an exclusively shearing bite. Similar to the dog, the upper P4 and the lower M1 are the largest teeth, referred to as carnassial, sectorial or shearing teeth. Due to this characteristic feature the dog and cat have a secodont dentition. The deciduous incisors are all present 15 days post partum, the canines erupt around day 18, the premolars between the 24th and 32nd after birth. Replacement of the deciduous teeth by the permanent set starts with 3.5 months and is completed after the 7th month.

Dentition of the ox

In the ox the upper incisors and canines are replaced by the dental pad and the lower canines are assimilated to the incisors. The incisors are simple, brachyodont teeth, which are designated from medial to lateral as central (I1), first intermediate (I2), second intermediate (I3) and corner incisors (I4) (Fig. 7-35 to 40). They are relatively loose within their alveolar sockets and fall easily out in older animals, where often only roots remain in the jaw. A wide diastema separates the incisors from the cheek teeth and makes it easy to grasp the tongue for examination of the mouth.

The deciduous incisors and premolars are either present at birth or erupt within the first two weeks.

Eruption times of permanent bovine incisors are:

- I1: 1.5 years,
- I2: 2.5 years,
- I3: 3.5 years and
- I4: 4 years.

The cheek teeth increase in size from front to back. These teeth are hypselodont teeth Attrition of the crowns is compensated for time by their continuing growth. When growth ceases, the roots are formed and the height of the clinical, exposed crown is maintained by gradual extrusion of the embedded part until the tooth is eventually consumed in old animals.

Dentition of the pig

The most striking feature of the porcine dentition are the large, curved canine teeth or tusks, which grow continuously throughout life (Fig. 7-41). The occlusal surface of the cheek teeth is made irregular by numerous tubercles and is ideal for crushing food.

Many farmers cut off the deciduous incisors and canines shortly after birth, which often results in medical problems.

Temporomandibular joint (articulatio temporomandibularis)

The temporomandibular joint is the synovial joint between the mandibular ramus and the squamous part of the temporal bone. It is a **condylar joint** (articulatio condylaris), whose articulating surfaces do not entirely correspond with each other. To compensate for this incongruency a **fibrocartilagenous disc** (discus interarticularis) is interposed between the articulating surfaces. It is relatively thick in herbivores, thin in the dog and either reduced to a very thin membrane or absent in the cat.

The temporomandibular joint is formed by the head of the condyloid process of the **mandible** (caput mandibulae) and the tripartite articular area of the temporal bone; the articular tubercle rostrally, the **mandibular fossa** (fossa mandibularis) with its transverse articular surface in the middle and the **retroarticular process** (processus retroarticularis) caudally. The **joint capsule** extends from the free margins of the articular surfaces and attaches to the entire edge of the disc. Thus the joint cavity is completely divided into a larger dorsal and a smaller ventral compartment. The **outer fibrous layer** of the joint capsule (stratum fibrosum) is strengthened by the **tight lateral** (ligamentum laterale) in all species and the **caudal ligament** (ligamentum caudale), which extends between the retroarticular process and the base of the coronoid process. The caudal ligament is not present in carnivores and the pig. The main movements of the temporomandibular joint are up and down, to open and close the mouth. A limited degree of lateral grinding and forward and backward movements of the mandible is possible in herbivores. The species specific variations are based on the pattern of mastication and are influenced by the masticatory muscles.

The **intermandibular joint** (articulatio intermandibularis) is the median osseous junction, uniting the right and left mandibular bodies (sutura intermandibularis), which takes the form of a synostosis in the pig and horse, but has a certain mobility in ruminants and in the dog.

Muscles of mastication

The muscles that are responsible for mastication are strong and show marked species specific variations due to the different anatomy of the whole masticatory apparatus, including the skeletal components, the teeth and the temporomandibular joint.

The masticatory muscles comprise those muscles, which elevate the mandible, thus closing the mouth:

- Masseter muscle (m. masseter),
- Medial pterygoid muscle (m. pterygoideus medialis),
- Lateral pterygoid muscle (m. pterygoideus lateralis),
- Temporal muscle (m. temporalis).

These muscles are derived form the first branchial arch, thus they receive their nerve supply by the mandibular branch of the trigeminal nerve.

The **masseter muscle** is a broad multipennate muscle with multiple tendinous intersections. It originates from the ventral border of the zygomatic arch and the facial crest and inserts on the lateral aspect of the mandible, extending from the facial notch to the temporomandibular joint. If the masseter muscles of both sides act together they force the upper and lower jaw together, if acting singly it carries the mandible to the side of the contracting muscle, which is essential for the grinding process of herbivores. In canines, where the chief jaw movement is scissor-like, the masseter muscle is relatively weak.

The **pterygoid muscles** pass from the base of the skull to the medial aspect of the mandible. They complement the masseter in its action. If contracting bilaterally they raise the mandible, if acting unilaterally they draw the mandible to the side of the contracting muscle. The lateral portion is also able to move the mandible rostrally, especially when the mouth is opened.

The **temporal muscle** occupies the temporal fossa, its size varying in the different species depending on the size of the fossa. It originates from the temporal crest, which forms the border of the temporal fossa, and from the temporal fascia and inserts on the coronoid process of the mandible. It is the strongest muscle of the head of carnivores. It raises the mandible, acting together with the other masticatory muscles.

Another muscle, that plays some part in jaw movements, particularly in opening the mouth, is the **digastric muscle,** which is not normally included under the term "muscle of mastication". Although named the **digastric muscles** (m. digastricus), it is a single bellied muscle in domestic animals, except in the horse, which has a caudal and a rostral belly. In the other domestic mammals its evolutionary bipartite structure is indicated by a fibrous intersection.

The rostral part is innervated by a branch of the **mandibular nerve** (n. mandibularis), the caudal part by the digastric branch **facial nerve** (n. facialis). It extends between the paracondylar process of the occiput and the medial surface of the mandible. In the horse the caudal belly branches to form a **lateral portion** (pars occipitomandibularis), which inserts on the angle of the mandibular and pulls the mandible backward. It has an intermediate round tendon, which perforates the tendon of insertion of the stylohyoid muscle. After passing beneath the basihyoid bone it forms the rostral belly, which attaches to the medial surface of the ventral border of the body of the mandible. The digastric mucle depresses the mandible and opens the mouth.

Pharynx (cavum pharyngis)

The pharynx is the common cavity through which both air and ingested material pass. It connects the oral cavity with the esophagus and the nasal cavity with the larnyx. It is bordered by the base of the skull and the two cranial cervical vertebrae dorsally, the larynx ventrally and the mandible, the pterygoid muscles and the suspensory part of the hyoid apparatus laterally (Fig. 7-43 and 47).

It can be divided into three parts:

- Nasopharynx (pars nasalis pharyngis seu pars respiratoria pharyngis),
- Oropharynx (pars oralis pharyngis),
- Laryngopharynx (pars laryngea pharyngis).

Fig 7-42. Paramedian section of the neck and head of a cat (König, 1992).

The **soft palate** (palatinum molle, velum palatinum) separates the rostral part of the pharnyx into a dorsal and ventral portion. The part above the soft palate is referred to as the nasopharnx, the ventral compartment as the oropharynx. The two portions meet in the **intrapharyngeal opening** (ostium intrapharyngeum), which is formed by the free border of the **soft palate** (arcus veli palatini) and the **palatopharyngeal arches,** which connect the soft palate to adjacent structures caudally. The caudal continuation, common to both, the nasopharynx and the oropharynx, is known as the **laryngopharynx.** The **nasopharynx** extends dorsal to the soft palate from the choanae to the intrapharyngeal opening. It is lined by respiratory mucosa and does not take part in the swallowing process, but forms the passive pathway for airflow (Fig.7-47). In ungulates the nasopharynx extends caudodorsally to form the pharyngeal recess. In the pig a blind-ending, mucosal pouch, the pharnygeal diverticulum, arises from the pharyngeal wall dorsal to the entrance of the esophagus.

The **isthmus of the faucium** extends ventral to the soft palate from the oral cavity to the intrapharyngeal opening. It is bordered dorsally by the soft palate, ventrally by the root of the tongue and laterally by the palatoglossal arches, a pair of folds from the soft palate to the adjacent tissue. It is lined by the stratified squamous epithelium of the oral mucosa.

The **laryngopharynx** extends from the intrapharyngeal opening to the entrance of the esophagus and the larynx. The epiglottis protrudes into the laryngopharynx and is flanked by the piriform recesses on either side, which serve as gutters for fluids. The caudal part of the laryngopharynx, which ends with the entrance into the esophagus, is referred to as the esophageal part of the pharynx. In the dog the pharyngoesophageal junction is marked by an **annular mucosal boundary** (limen pharyngooesophageum). Several openings form into the pharyngeal cavity:

- Paired choanae between the nasal cavity and the nasopharynx,
- Isthmus of the fauces (isthmus faucium) between the oral cavity and the oropharynx,
- Entrance into the auditory (Eustachia) tubes, connecting the nasopharynx and the middle ear,
- Entrance into the larynx (aditus laryngis) and
- Entrance into the esophagus (aditus oesophageus).

The wall of the pharynx is formed by striated muscles (muscles of the pharynx), which can be grouped into three categories based on their action: constriction, dilatation and those which shorten the pharynx. The constrictor muscles arise from certain fixed points to each side of the pharynx, run onto the roof of the pharynx and form a series of arches that enclose the lumen dorsally and laterally.

The constrictor muscles can be subdivided into:

- **Rostral constrictor muscles:**
  - Pterygopharyngeal muscles (mm. pterygopharyngei) originating from the pterygoid,
  - Palatopharyngeal muscle (m. palatopharyngeus) originating from the aponeurosis of the soft palate.

The rostral constrictor muscles have many fibres, which are orientated in a longitudinal direction, thus assist in shortening the pharynx.

Fig 7-43. Paramedian section of the neck and head of a dog.

- **Middle constrictor muscle:**
  – Hyopharyngeal muscle (m. hyopharyngeus), originating from the hyoid bone.
- **Caudal constrictor muscles:**
  – Thyropharyngeal muscle (m. thyropharyngeus), originating from the thyroid cartilage,
  – Cricopharyngeal muscle (m. cricopharyngeus), originating from the cricoid cartilage.

In contrast to the group of constrictor muscles, there is only a single muscle responsible for dilating the pharynx: the caudal stylopharyngeal muscle, which arises from the hyoid bone to fan out in the pharyngeal wall.

Deglutition (swallowing)

Deglutition describes the process by which a bolus of food is transfered from the oral cavity through the pharynx into the esophagus and finally into the stomach. It can be divided into two stages. The first stage is the voluntary act of mastication and the passage of the bolus of food into the oropharynx. This action involves a wave-like motion of the tongue against the palate, caused by the contraction of the mylohoid, hyoglossal and styloglossal muscles while the jaws are closed. The second stage is initiated when the food bolus touches the pharyngeal mucosa, initiating reflexes of swallowing. The soft palate is elevated against the roof of the nasopharynx and the muscle bundles inside the palatopharyngeal arches contract, thus closing the intrapharyngeal opening. The tongue is raised, pressing against the soft palate to prevent food from re-entering the oral cavity. At the same time the hyoid apparatus and the larynx are simultaneously drawn forward and the epiglottis is drawn back, protecting the laryngeal entrance. At this stage breathing is inhibited and the food passes over the epiglottis or in the case of fluids to each side of it. The ingested material is propelled into the esophagus by the successive contractions of the three contractors of the pharynx.

Lymphatic structures of the pharynx (tonsils)

The pharyngeal walls contain a large amount of lymphoreticular tissue, which aggregates to form **lymph nodules** or **tonsils.** Tonsils consist of a multitude of subepithelial lymph nodules surrounded by a common soft-tissue capsule and have efferent lymphatics only. They form a ring of lymphatic tissue around the pharynx which provides an immunological barrier to protect the respiratory and alimentary systems. The pharyngeal tonsils can be grouped into palatine, pharyngeal, lingual, choanal and tubal tonsils based upon their location (Fig. 7-45 and 46).

The **lingual tonsil** (tonsilla lingualis) is located on either side of the root of the tongue and is especially well developed in the horse and the ox.

The **palatine tonsil** (tonsilla palatina) is situated in the lateral wall of the oropharynx. In carnivores it is located within a tonsillar fossa, the medial wall of which is formed by a falciform fold from the soft palate, the tonsillar fold. Surgical removal of the palatine tonsil is indicated in some animals **(tonsillectomy).** It is not present in the pig. Another tonsil lies within the mucosa on the ventral surface of the soft palate and is especially well-developed in the horse and the pig. The pharyngeal tonsil is located on the roof of the nasopharyx. The

Fig 7-44. External musculature of the pharynx of an ox, lateral aspect (courtesy of Dr. R. Macher, Vienna).

tubal tonsil is situated close to the entrance of the auditory tube in ruminants and the pig.

Muscles of the hyoid apparatus

The muscles of the hyoid apparatus have a close functional relationship to the muscles of the tongue and pharynx. They assist deglutition by pulling the larynx first rostrally and then caudally. They can be divided into the upper and lower muscles of the hyoid apparatus. Upper muscles of the hyoid apparatus:

- Mylohyoid muscle (m. mylohyoideus),
- Geniohyoid muscle (m. geniohyoideus),
- Stylohyoid muscle (m. stylohyoideus),
- Occipitohyoid muscle (m. occipitohyoideus),
- Ceratohyoid muscle (m. ceratohyoideus) and
- Transverse hyoid muscle (m. hyoideus transversus).

The **mylohyoid muscle** has already been described with the musculature of the tongue. It extends subcutaneously from the

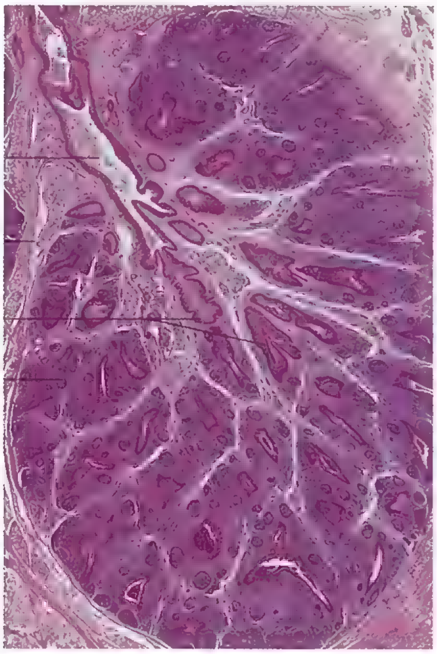

Fig 7-45. Histological section of the palatine tonsil of an ox (Liebich, 2004).

Fig 7-46. Histological section of a tonsillar fossa in a dog (Liebich, 2004).

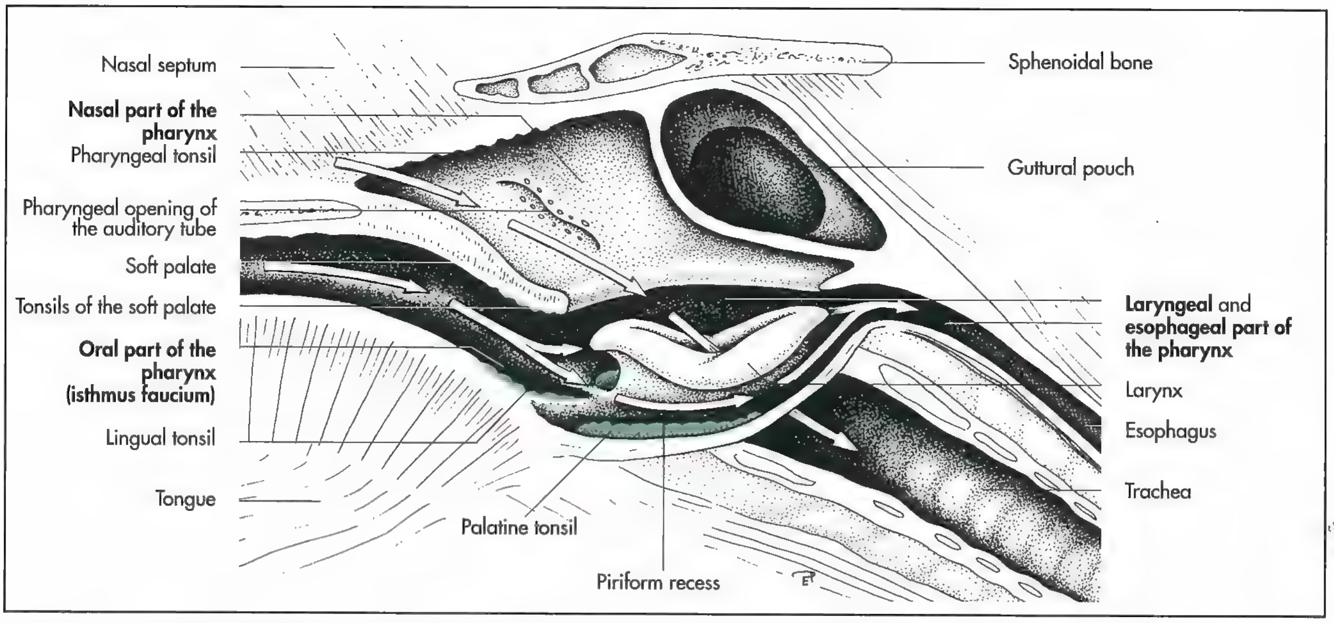

Fig 7-47. Lymphatic tissue of the pharynx of the horse, illustrating the crossing of the nasal and oral passages, longitudinal sections, schematic.

mylohyoid line on the medial aspect of the mandible to meet its contralateral counterpart in a median raphe and attaches to the body and the lingual process of the hyoid bone. The two bodies suspend and elevate the tongue (Fig. 7-13). It is innervated by the mandibular branch of the trigeminal nerve.

The spindle-shaped **geniohyoid muscle** passes dorsal to the mylohyoid muscle from the incisive part of the mandible to the body and the lingual process of the mandible. It draws the hyoid and thus the tongue and larynx forward (Fig. 7-13).

The **stylohyoid muscle** originates from the caudal third of the stylohyoid and in the cat and dog from the temporal bone. It inserts on the thyrohyoid and is able to move the hyoid bone and the larynx caudodorsally. In the horse its tendon of insertion forms a sling through which the intermediate tendon of the digastricus muscle passes.

The **occipitohyoid muscle** is a flat muscle, which originates from the paracondylar process of the occipital bone and inserts on the caudal end of the stylohyoid. It moves the rostral end of the stylohyoid and thus the larynx ventrally.

The **ceratohyoid muscle** is a thin triangular muscular sheet, which arises from the rostral margin of the thyrohyoid and inserts on the caudal margin of the ceratohyoid. It elevates the thyrohyoid and draws the larynx rostrodorsally.

The **transverse hyoid muscle** arises from the ceratohyoid and meets its contralateral counterpart in an indistinct median raphe. It is a rather weak muscle and is absent in the dog, cat and pig. The nerve supply of the upper muscles of the hyoid apparatus, with the exception of the mylohyoid muscle, is provided by the ventral branches of the first two cervical nerves and the hypoglossal nerve.

Lower muscles of the hyoid apparatus

The lower hyoid muscles can be regarded as the cranial continuation of the rectus abdominis muscle and are described in detail in chapter 2. This group comprises three pairs of muscles:

- Sternohyoid muscle (m. sternohyoideus),
- Sternothyroid muscle (m. sternothyroideus),
- Omohyoid muscle (m. omohyoideus).

The **sternohyoid muscle** is a strong straplike muscle, which originates from the manubrium of the sternum and the first rib (carnivores) and inserts on the basihyoid bone. It meets its contralateral pair on the midline of the neck and they extend cranially, covering the ventral surface of the trachea. Its caudal half is fused to the sternothyroid muscle.

The **sternothyroid muscle** separates from the sternohyoid in the middle of the neck and inserts on the thyroid cartilage of the larynx. Both muscle pairs pull the hyoid bone, the larynx and the tongue caudally during deglutition.

The **omohyoid muscle** is developed most in the horse and is absent in carnivores. It originates from the subscapular fascia, close to the shoulder joint in the horse and from the deep fascia of the neck in ruminants and inserts on the basihyoid bone. In the horse, the omohyoid muscle unites with the corresponding muscle of the opposite side midway up the neck and inserts together with the sternohyoid muscle on the lingual process of the hyoid bone. In the cranial half of the neck it is positioned between the external jugular vein and the common carotid artery, thus providing some protection for the latter during intravenous injection in that part of the neck.

The upper hyoid muscles dilate the pharynx by pulling the hyoid bone, the tongue and the larynx caudally. If these muscles are passively tensed by elevating head and neck to administer intraoral medication, deglutition cannot be performed properly and medication may pass into the trachea or the nasal cavity. These muscles are also innervated by the ventral branches of the first two cervical nerves.

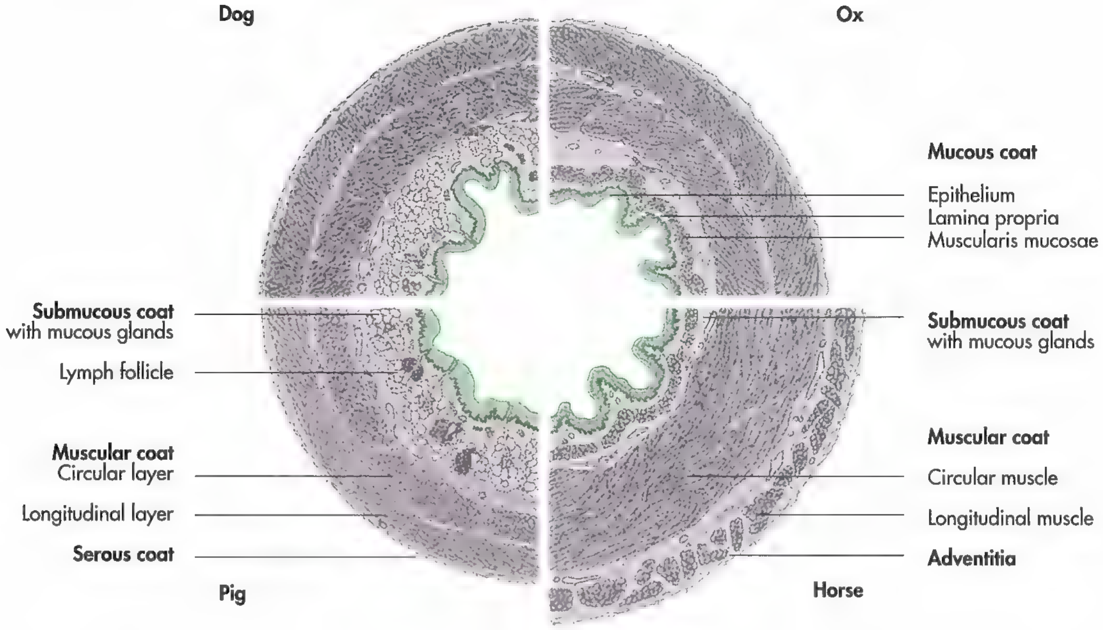

Fig 7-48. Transverse section of the esophagus of the dog, pig, horse and dog, schematic (Liebich, 2004).

Cranial part of the alimentary canal (esophagus and stomach)

Esophagus

The esophagus or gullet is the tube between the pharynx and the stomach. It begins dorsal to the cricoid cartilage of the larynx and ends at the cardia of the stomach. At its origin it passes to the left of the trachea, so that at the thoracic inlet it comes to lie on the left lateral aspect of the trachea.

Within the thoracic cavity it is located dorsal to the trachea and runs in the mediastinum, continuing beyond the tracheal bifurcation and over the base of the heart . It continues ventral to the ascending aorta with a slight dorsal inclination and enters the abdominal cavity through the oesophageal hiatus of the diaphragm, flanked by the ventral and dorsal trunk of the vagus. It passes over the dorsal border of the liver to join the stomach at the cardia.

Since it traverses most of the neck, all of the thorax and ends on entering the abdomen it is divided into cervical, thoracic and abdominal portions. In ruminants and the horse, the lumen of the esophagus narrows at the thoracic inlet and the oesophageal hiatus of the diaphragm, which predisposes these species to choke at those sites. Carnivores, however, are prone to megaesophagus or dilatation of the esophagus before it enters the abdomen.

Structure of the esophagus

The structure of the esophagus conforms to a general pattern common to the remainder of the alimentary canal.

The esophagus has four layers, these are (from the inside to the outside):

- **Mucosa** (tunica mucosa):
  - Epithelium (epithelium mucosae),
  - Lamina propria (lamina propria mucosae),
  - Muscular layer of mucous membrane (lamina muscularis mucosae),
- **Submucosa** (tela submucosa),
- **Muscular layer** (tunica muscularis):
  - Circular muscle layer (stratum circulare),
  - Longitudinal muscle layer (stratum longitudinale),
- **Adventitia** (tunica adventitia) in the cervical portion, **serosa** (tunica serosa) in the thoracic portion (pleura) and abdominal portion (peritoneum) (Fig. 7-48).

The **superficial layer of the mucosa** is composed of a superficially cornified, stratified squamous epithelium, with the degree of keratinisation varying between species according to the coarseness of their diet. The submucosa loosely connects the mucosa with the muscular layers, thus allowing the mucosa to be thrown into longitudinal folds, when the esophagus contracts. These folds can be visualised with contrast radiography and endoscopy. The submucosa contains mucous glands on its entire length in the dog, in the

first cranial half in the pig and at the beginning of the esophagus only in the other domestic mammals.

The **muscular layers** consists of two muscle strata, an outer longitudinal layer and an inner circular layer. Both layers are spiral and they wind in opposite directions in the first part of the esophagus, but closer to the stomach the outer layer becomes more longitudinal and the inner one more circular.

The muscular layers consists of striated muscle over the whole length of the esophagus in ruminants and in the dog, in the pig the most caudal part of the esophagus is smooth muscle and in the horse and the cat only the first two thirds of the esophagus is striated muscle, while the caudal third is smooth muscle.

The **muscular layer** forms the cardiac sphincter (m. sphincter cardiae), where the esophagus joins the stomach. Successive contraction of the muscular layers cause peristaltic waves, which propell food from the pharynx to the stomach. Antiperistaltic contractions are responsible for regurgitation in ruminants and vomiting in the other domestic mammals.

The **outer layer of the cervical portion** of the esophagus is adventitia, loose connective tissue, which connects the esophagus with adjacent tissue in a mobile fashion. The **adventitia** is replaced by serosa in the thorax and in the abdomen. A more detailed description can be found in histology textbooks.

The esophagus receives its innervation from the sympathetic and vagus nerves. Lymphatics drain into the deep cervical lymph nodes (lymphonodi cervicales profundi) and into the mediastinal lymph nodes (lymphonodi mediastinales).

Stomach (gaster, ventriculus)

The stomach is interposed between the esophagus and small intestine. In the domestic mammals the stomachs vary considerably in form and distribution of the different types of mucosa lining the stomach. Considering their form they can be divided into simple stomachs, which have only one compartment and complex stomachs with several compartments (Fig. 7-49).

The mucosal lining of glandular stomachs are lined by glandular mucosa with a simple columnar epithelium. Composite stomachs, have an area of glandular mucosa, and another lined by a non-glandular mucosa covered by a stratified squamous epithelium.

Cats and dogs have simple, glandular stomachs. The horse and the pig have simple, composite stomachs, whereby the majority of the stomach is lined by glandular mucosa and a small cranial part by non-glandular mucosa. Ruminants have a complex, composite stomach, which comprises four compartments, three of which (rumen, reticulum, omasum) are lined by non-glandular mucosa and one lined by glandular mucosa (omasum).

Simple stomach

The simple stomach is a sac-shaped dilatation of the alimentary canal (Fig. 7-49 and Fig. 7-54 to 59). The major divisions of the stomach are the:

- Cardiac portion (pars cardiaca),
- Fundus (fundus ventriculi),
- Body (corpus ventriculi) and
- Pyloric portion (pars pylorica).

It possesses visceral and parietal surfaces and greater and lesser curvatures.

The inlet of the stomach is called the **cardia** and the outlet, the **pylorus,** both of which are controlled by **sphincters.** The cardia, where the esophagus joins the stomach lies to the right of the median plane of the abdomen, the pylorus, which continues into the duodenum, lies more to the left. The exact shape and position of the stomach depends on the degree of filling.

The **body** is the large middle portion of the stomach, which extends from the fundus on the left to the pylorus on the right. The **pyloric** part can be divided into the expanded **pyloric antrum** (antrum pyloricum) and the **pyloric canal** (canalis pyloricus) towards the duodenum. The fundus is a blind outpocketing rising above the body and the cardia. It has the form of a rather **large sac** (saccus caecus) in the horse and forms the ventricular **diverticulum** in the pig.

The **parietal surface** (facies parietalis) of the stomach lies against the diaphragm and the liver, whereas the **visceral surface** (facies visceralis) is in contact with the adjacent abdominal organs caudal to it.

The **greater curvature** (curvatura ventriculi major) is the convex, ventral border of the stomach extending from the cardia to the pylorus, which gives attachment to the greater omentum. The **lesser curvature** is the concave dorsal border of the stomach and also runs from the cardia to the pylorus (Fig. 7-54 and 57). It is connected to the liver by the lesser omentum. The lesser curvature is not evenly concave, but marked by the **angular notch** (incisura angularis). In some individuals, especially cats, this notch is rather pronounced and might cause difficulties during gastroscopy.

Structure of the gastric wall

The general architecture of the gastric wall corresponds to that of the esophagus. It is composed of the following layers from the inside to the outside:

- Mucosa (tunica mucosa),
- Submucosa (tela submucosa),
- Muscular layer (tunica muscularis) and
- Peritoneum (serosa seu lamina visceralis).

The **mucosa** close to where the esophagus joins the stomach is non-glandular, whereas glandular mucosa lines the rest of the stomach. The non-glandular mucosa is whitish and often slightly folded, its surface consists of a cornified stratified squamous epithelium. In the horse the junction between the non-glandular and the glandular mucosa is marked by a ridge, the **plicate border** (margo plicatus) (Fig. 7-60). The **glandular mucosa** forms folds and is marked by a multitude of grooves and pits, which can only be seen under the microscope (foveolae gastricae). The stomach can be divided into three regions based on the species-specific distribution of different types of **gastric glands** (glandulae gastricae) (Fig. 7-49 to 52):

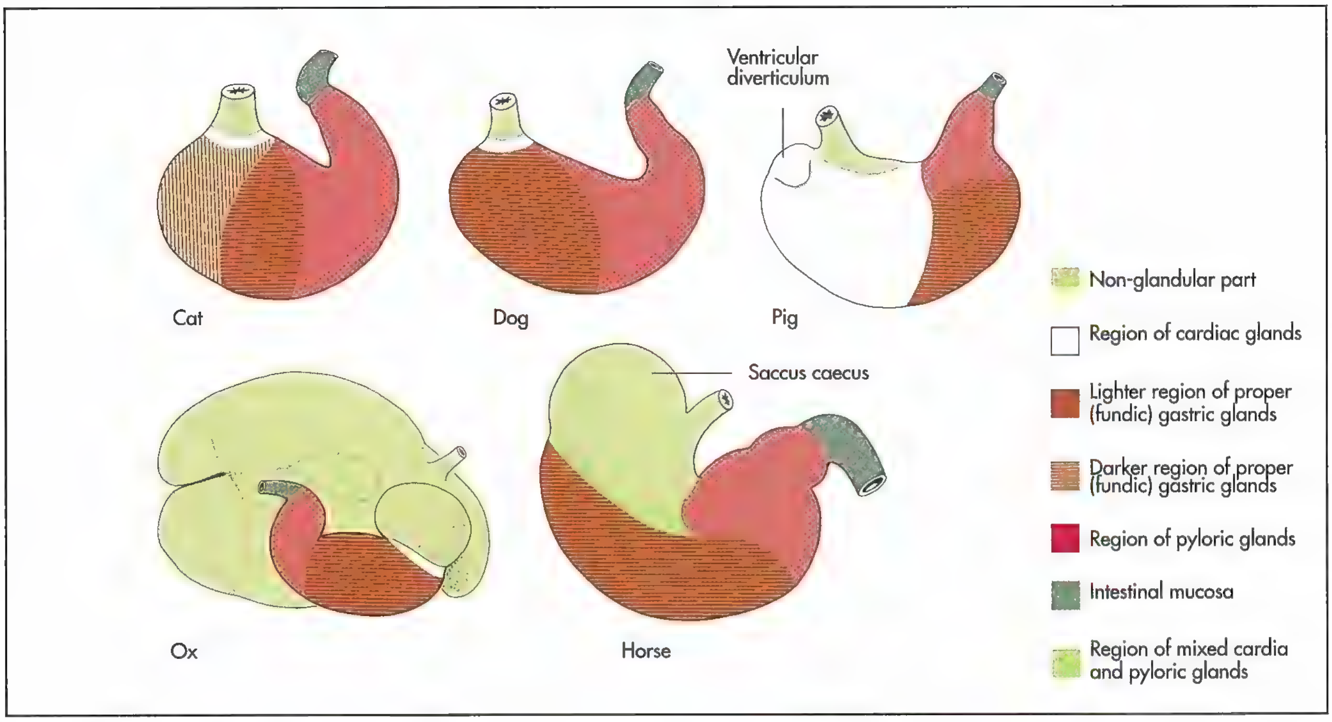

Fig 7-49. Distribution of the gastric mucosa in the domestic mammals, schematic (Liebich, 2004).

- Region of the cardiac glands (gll. cardiacae),
- Region of the proper (fundic) gastric glands (gll. gastricae propriae),
- Region of the pyloric glands (gll. pyloricae).

The **region of the cardiac glands** is a narrow zone around the cardia on most animals, except the pig, in which it is rather extensive (Fig. 7-49 and 50).

Pyloric glands (Fig. 7-49 and 52) are found in the mucosa of the pyloric part of the stomach, the proper or fundic glands (Fig. 7-49 and 51) in the fundus and body.

The **gastric glands** differ in the nature of secretion they produce: the cardiac and pyloric glands function mainly to produce mucus, which provides a protective barrier for the mucosa against the gastric juice by lining the inner surface of the stomach and by buffering the acid gastric juice.

Three different types of cells are found in the region of the proper (fundic) gastric glands. **Neck cells,** which are located in the neck of the glands produce mucus and serve as reserve cells to replace epithelial cells. **Chief cells** produce pepsinogen, the precursor for pepsin. **Parietal cells** are the source of chloride and hydrogen ions and an intrinsic factor, which is essential for the resorption of vitamin B_{12} in the ileum. (A more detailed description can be found in histology and physiology textbooks.)

The **submucosa** consists of a strong, but thin layer of areolar tissue. It is separated from the mucosa proper by a plexiform muscularis mucosae. It contains gastric arteries, veins and nerves, fat, lymphatic tissue and collagenous and elastic fibres. The latter assist the muscularis mucosae to form folds characteristic of the empty organ. These folds are predominantly longitudinal in orientation and start to disappear when the stomach is distended.

Since the **muscular layer** of the stomach plays an important role in mixing the food with the gastric juice and finally transferring it to the small intestine, its structure varies in the different parts of the stomach. It essentially consists of two layers of smooth muscle:

- **Inner circular layer** (stratum circulare), which forms the
  - Cardiac sphincter (m. sphincter cardiae),
  - Pyloric sphincter (m. sphincter pylori),
- **Outer longitudinal layer** (stratum longitudinale)
  - Longitudinal fibres (fibrae longitudinales),
  - External oblique fibres (fibrae oblique externae) and
  - Internal oblique fibres (fibrae obliquae internae).

The **outer longitudinal layer** is continuous with the outer longitudinal layer of both the esophagus and duodenum (Fig.7-53) and is concentrated along the curvatures of the stomach.

The **inner circular layer** is more complete than is the longitudinal layer. At the cardia it is thickened to form the feeble **cardiac sphincter.** The circular layer is well developed as it surrounds the pyloric canal, especially in the pig, where it protrudes into the lumen to form the **torus pyloricus.** The pylorus is also surrounded by a circular muscle termed the **pyloric sphincter** (Fig. 7-61). The innermost oblique fibres do not

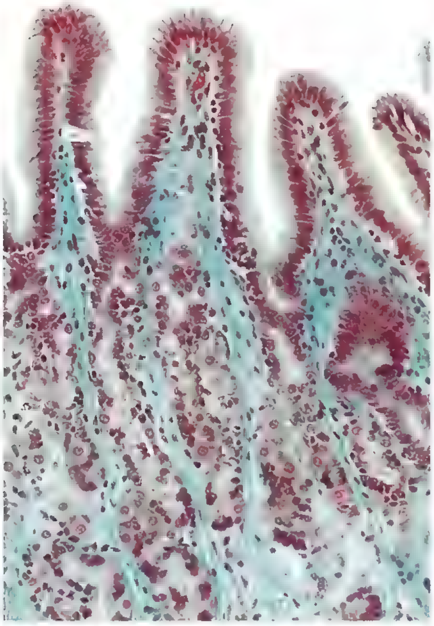

Fig 7-50. Section of the cardiac gland region in the stomach of a dog, showing cardiac glands in the proper lamina and foveolae gastricae.

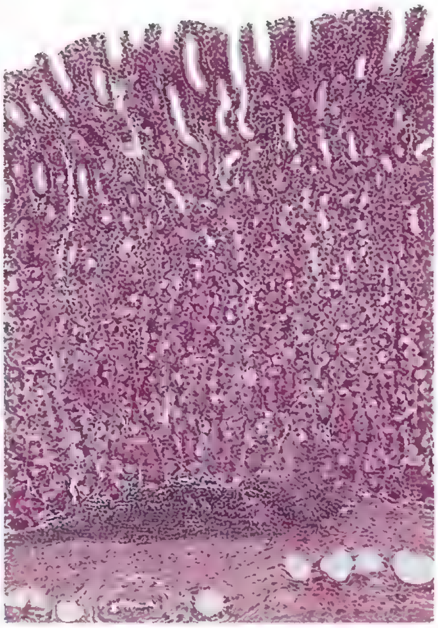

Fig 7-51. Section of the fundic gland region in the stomach of a dog showing the long tubular proper gastric glands in the proper lamina.

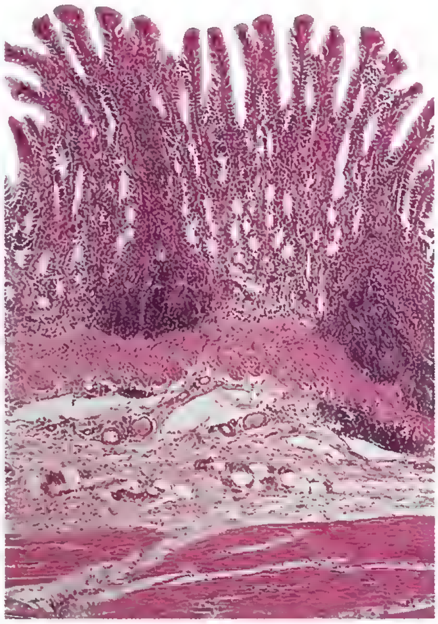

Fig 7-52. Section of the pyloric gland region in the stomach of a dog showing pyloric glands in the proper lamina.

form a complete layer (Fig. 7-53), but compensate for the deficiencies in the circular layer. Particularly strong bundles arch around the cardia of the horse, which is one of the reasons, why a horse cannot vomit easily.

The **visceral serosa** (serosa seu lamina visceralis peritonei) covers the entire organ, adhering to the underlying muscle except along the curvatures where it is reflected to continue into the omenta. The greater and lesser omentum are special derivatives of the **connecting serosa** (serosa intermedia), which consists of double sheets of serosal membranes extending from the stomach to the **parietal serosa** (lamina parietalis peritonei).

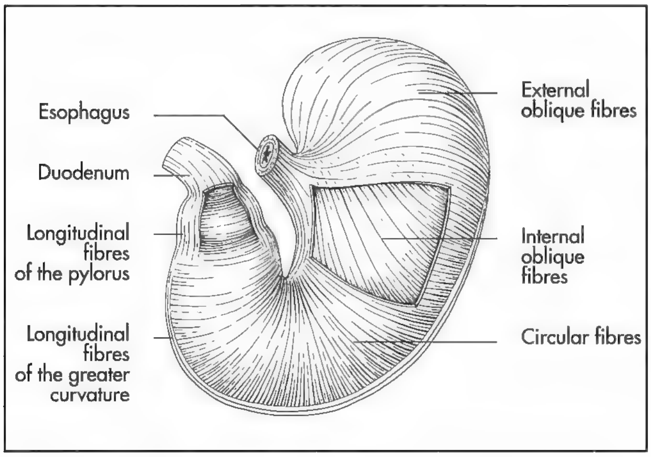

Fig 7-53. Muscular coat of the stomach of a horse, illustrating its different layers, schematic (Schaller, 1992).

Species specific variations of the simple stomach

Dog: The empty or partly filled stomach is shaped like a "C" with its convex surface facing caudoventrally and to the left (Fig. 7-49, 57 and 58). The funnel-shaped cardia is rather wide, which may be related to the ease with which dogs vomit. Gastric volvulus is relatively common, especially in large breeds. The non-glandular region and the cardiac gland region are limited to a circular zone around the entrance of the esophagus (Fig. 7-49).

Cat: The stomach of the cat is also C-shaped, but has a narrower lumen than that of the dog (Fig. 7-54). The angular notch is comparatively deep. The distribution of the gastric glands is similar to that of the dog.

Pig: The stomach of the pig is characterised by the presence of a diverticulum surmounting the fundus. The non-glandular area surrounds the cardiac opening and extends to the diverticulum of which it lines a small part. The major part of the diverticulum is lined by glandular mucosa. The region of the cardiac glands is relatively large (Fig. 7-49 and 59). The pylorus is accentuated by a fleshy protuberance, the torus pyloricus.

Horse: The stomach of the horse is small in relation to the animal compared to other species. Its capacity is between 5-15l, which has to taken into account, when administering fluids via a nasogastric tube to avoid overdistension. The fundus is extended to form the saccus caecus. A rised edge, the plicate border divides the interior in a rather large non-glandular region, which occupies the fundus and part of the body and a glandular region (Fig. 7- 49, 60 and 61).

In some horses, the non-glandular region is marked by scars from the larvae of gastrophilus intestinalis. The cardiac sphinc-

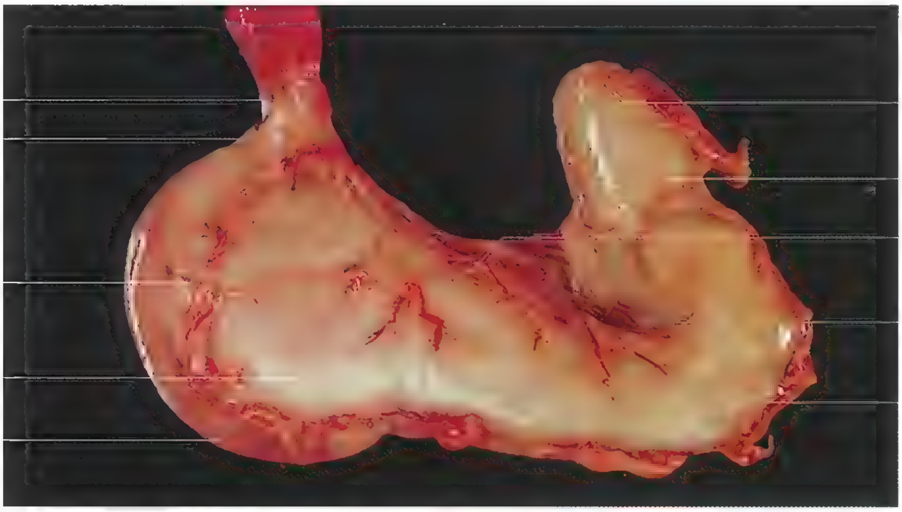

Fig 7-54. Stomach of a cat, caudal aspect.

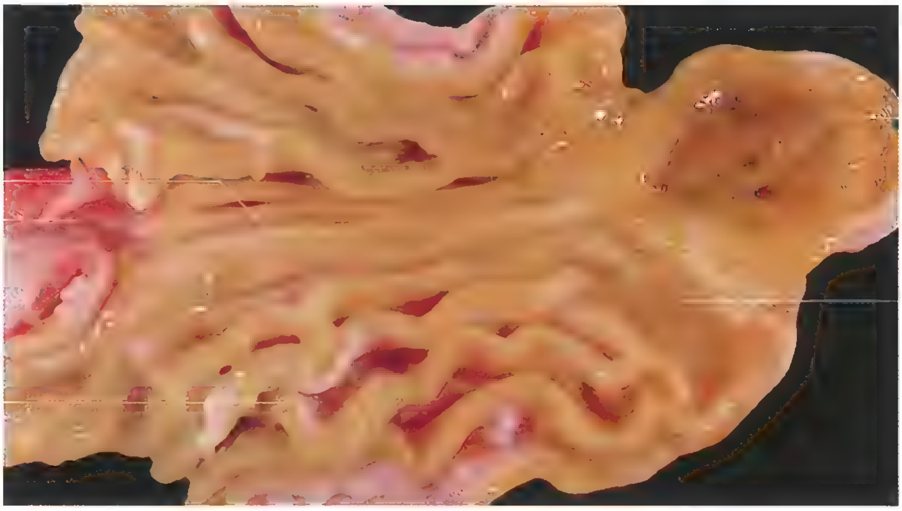

Fig 7-55. Stomach of a cat, interior (König, 1992).

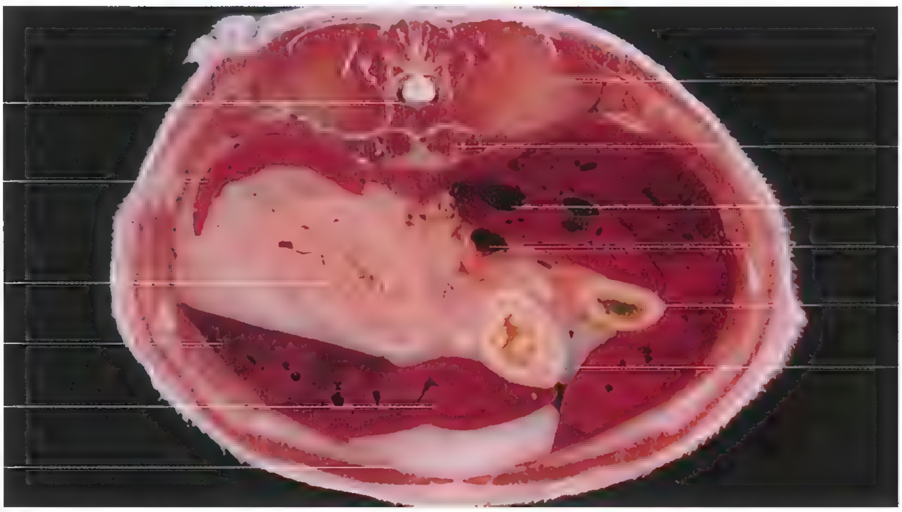

Fig 7-56. Transverse section of the abdomen of a cat at the level of the stomach, caudal aspect (König, 1992).

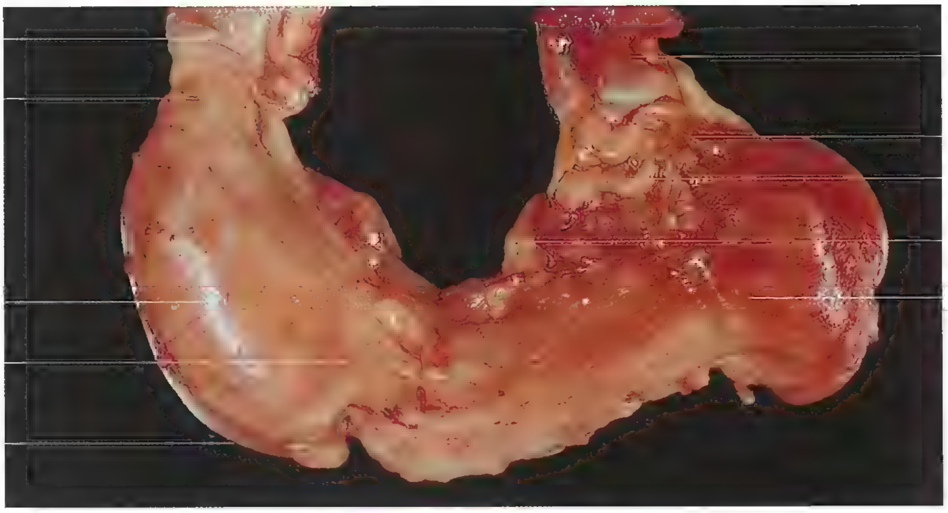

Fig 7-57. Stomach of a dog, caudal aspect.

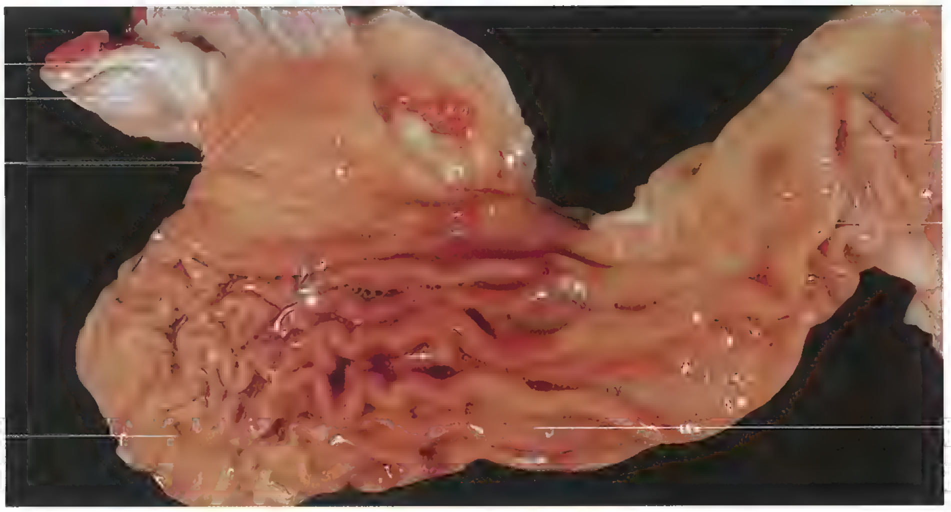

Fig 7-58. Stomach of a dog, interior.

Fig 7-59. Stomach of a pig, cardiac region, interior.

Fig 7-60. Stomach of a horse, cardiac region, interior.

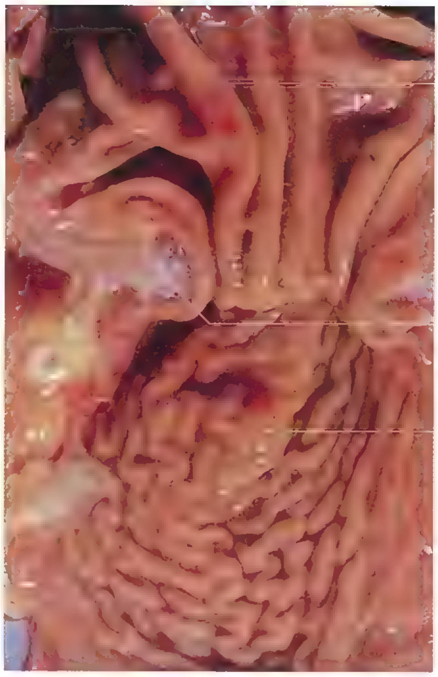

Fig 7-61. Stomach of a horse, pyloric region, interior.

ter is especially well developed and this, together with the oblique entrance of the esophagus is thought to be responsible for the horse's reputed inability to vomit. However, vomiting and regurgitation, although rare is possible.

Blood supply and innervation

The blood supply of the simple stomach comes from all three main branches of the **celiac artery** (a. coeliaca) (Fig. 7-62, Fig. 12-33 and 34):

- **Left gastric artery** (a. gastrica sinistra),
- **Hepatic artery** (a. hepatica),
  - Right gastric artery (a. gastrica dextra),
  - Right gastric gastroepiploic artery (a. gastroepiploica dextra),
- **Splenic artery** (a. lienalis),
  - Left gastric gastroepiploic artery (a. gastroepiploica sinistra).

The **left** and **right gastric arteries** run along the lesser curvature, the left and right gastroepiploic arteries run along the greater curvature. Thus the blood supply is particularly generous along the two curvatures, while it is less in the middle of the parietal and visceral surface. This should be taken into account, when performing gastrotomy.

The **left gastric artery** is a direct branch of coeliac artery and is the largest of the arteries supplying the stomach. On reaching the lesser curvature it divides into a branch for each gastric surface and vascularises the major part of the stomach. It forms anastomoses with the right gastric artery and with the esophageal artery.

The second branch of the celiac artery is the **hepatic artery,** which provides blood supply to the liver, and also extends the right gastric and the right gastroepiploic artery to the stomach. The third main branch of the celiac artery, the **splenic artery,** which supplies the spleen, continues as the left gastroepiploic artery to the greater curvature, where the epiploic vessels anastomose with each other.

In addition to these arteries two or more branches (aa. gastricae breves) leave the terminal part of the splenic artery and supply a portion of the fundus of the stomach. In cases, where surgical removal of the spleen is indicated (splenectomy) the splenic artery should not be ligated completely to prevent impairment of the blood supply to the stomach. Because of the anastomoses of the gastric arteries with each other and the gastroepiploic arteries, which also anastomose with each other, a perigastric arterial ring is formed which includes the whole stomach except the left part of the fundus.

The **veins** have a similar arrangement than the arteries and ultimately join the **portal vein** (v. portae) to enter the liver. Anastomoses between the **esophageal vein** (v. oesophagea) and the **left gastric vein** (v. gastrica sinistra) function as portocaval shunts. Numerous arteriovenous anastomoses are thought to be responsible to regulate the blood supply to the gastric mucosa: in the empty stomach most blood is diverted away from the capillary bed.

Lymph vessels are present in profusion, especially in the submucosa. They eventually drain into several gastric lymph nodes, each receiving the lymphatics of a particular region.

The stomach is innervated by **parasympathetic fibres** from the vagal trunks and by **sympathetic fibres** that reach the organ with the arteries. The vagal part stimulates gastric secretion.

Fig 7-62. Arteries of the stomach of a dog, corrosion cast (König, 1992).

Position of the stomach

The position of the stomach is closely related to the development of the **greater omentum** (omentum majus) and the **lesser omentum** (omentum minus). From this particular situation of the mesentery the connestion of the stomach to adjacent organs can be derived. Principaly the following can be distinguished:

Dorsal mesogastrium:
- Greater omentum (omentum majus),
  - Bursal portion enclosing the omental bursa (bursa omentalis),
- Gastrophrenic ligament (lig. gastrophrenicum),
- Phrenicosplenic ligament (lig. phrenicolienale),
- Gastrosplenic ligament (lig. gastrolienale),
- Omental veil (velum omentale) in carnivores,
- Nephrosplenic ligament (lig. lienorenale) in the horse.

Ventral mesogastrium:
- Lesser omentum (omentum minus),
  - Hepatogastric ligament (lig. hepatogastricum),
  - Hepatoduodenal ligament (lig. hepatoduodenale)
- Falciform ligament (lig. falciforme).

The **greater omentum** develops from the dorsal mesentery of the stomach (mesogastrium dorsale), while the **lesser omentum** is derived from the ventral mesogastrium. In addition to the omenta there are several double-layered peritoneal folds extending between neighbouring organs, which are also derived from the dorsal and ventral mesogastrium.

The **greater omentum,** also referred to as epiploon, originates from the dorsal wall of the abdomen and attaches to the greater curvature of the stomach. It is drawn out caudally and folded on itself forming a pouch, the omental bursa, which encloses the **caudal omental recess** (recessus caudalis omentalis). The greater omentum has a lace-like appearance, due to the streaks of fat around the arteries that run through an otherwise transparent serous membrane. Its walls are described as **parietal** (also called superficial or ventral) and **visceral** (also called deep or dorsal) because of their relationship to abdominal wall and viscera. The parietal wall extends from the origin to the pelvic inlet, where it reflects back to reach the greater curvature of the stomach as the visceral wall. In carnivores it includes the left crus of the pancreas in its origin. The visceral wall encloses the spleen.

The adult arrangement of the greater omentum is determined by the longitudinal growth of the mesentery and the rotation of the gastrointestinal tract during development. This results in considerable variations between species with regards to size, position and capacity of the greater omentum. In carnivores and ruminants it runs caudally between the viscera and the abdominal floor to the pelvic inlet and back to the stomach. It is liable to be shifted around between organs and the ventral and lateral abdominal walls, and has an important role in controlling inflammation, thus protecting the abdominal organs. In the horse and pig it lies irregurlary between loops of intestine, but can also reach the pelvic inlet.

The omental bursa, the part of the peritoneal cavity enclosed in the greater omentum, is a flat pouch, that has two compartments:

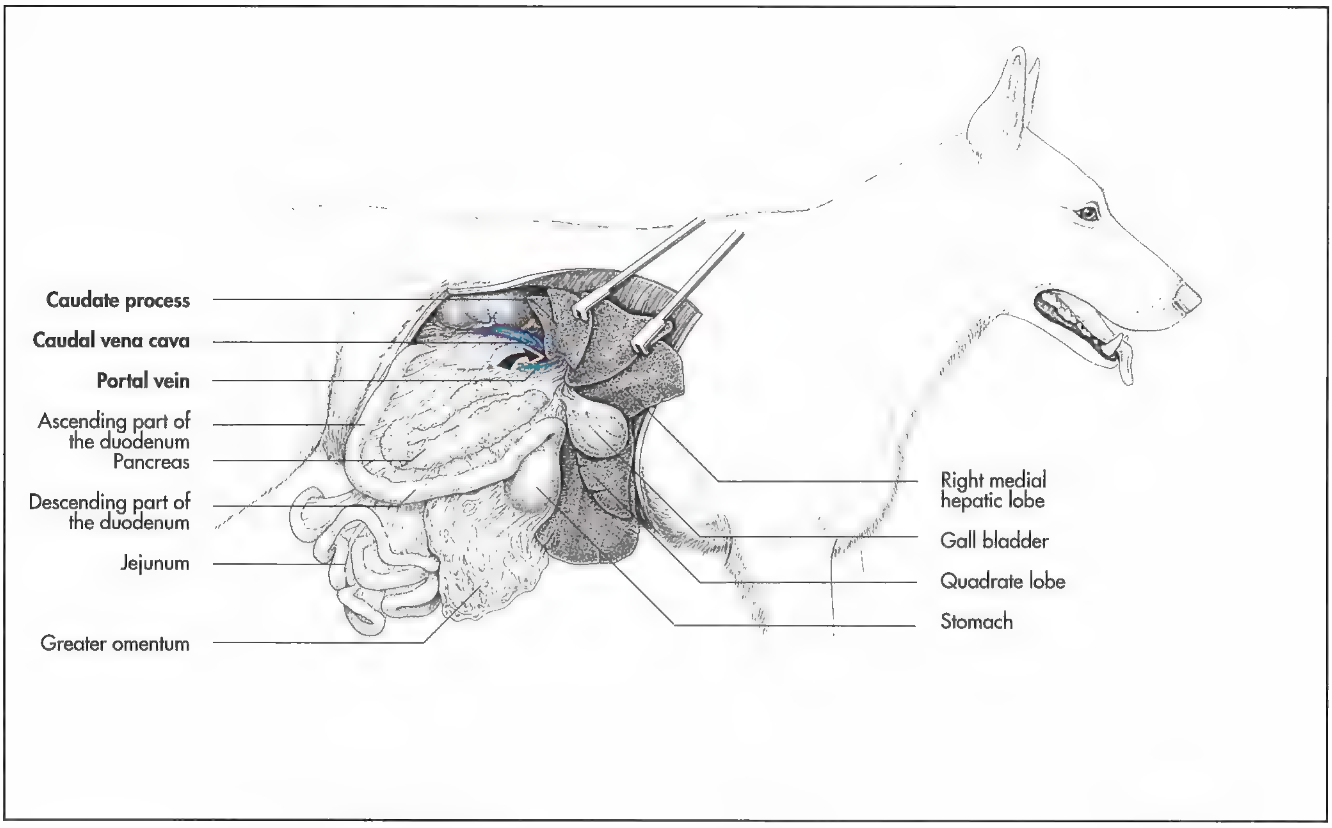

Fig. 7-63. Position of the epiploic (omental) foramen in the dog (arrow), schematic.

- Vestibule of the omental bursa (vestibulum bursae omentalis),
- Caudal omental recess (recessus caudalis omentalis).

Access to the interior of the vestibule of the omental bursa is reduced to the narrow **epiploic (omental) foramen** through which the cavity of the omental bursa remains in open communication with the major part of the peritoneal cavity. Vestibule and caudal recess communicate freely over the lesser curvature of the stomach. The **epiploic foramen** is bounded ventrally by the peritoneum covering the portal vein and dorsally by that covering the caudal vena cava (Fig. 7-63). Entrapment of intestine in the epiploic foramen can cause colic in the horse. In addition to the **greater omentum** there are several double-layered peritoneal folds extending between neighbouring organs, which are also derived from the **dorsal mesogastrium:**

- **Gastrophrenic ligament** (lig. gastrophrenicum) and **phrenicosplenic ligament** (lig. phrenicolienale) between the left crus of the diaphragm and the stomach and spleen. Its ventral part encloses the abdominal portion of the esophagus,
- **Gastrosplenic ligament** (lig. gastrolienale) between the spleen and stomach,
- **Omental veil** (velum omentale), which is present in carnivores only, is a rectangular portion of the dorsal mesentery extending on the left side of the abdomen between the spleen and the mesentery of the duodenum and
- **Nephrosplenic ligament** (lig. lienorenale) in the horse is the caudal extension of the phrenicosplenic ligamen; displacement of intestines over this ligament is a common cause of colic.

The **lesser omentum** is the largest derivative of the **ventral mesogastrium,** but is not nearly as large as the greater omentum, which it resembles in structure. It loosely spans the distance from the lesser curvature of the stomach to the porta of the liver and attaches to the abdominal floor, the line of attachment extending from the diaphragm to the umbilicus. It is continuous with the cranial mesoduodenum and attaches to the margin of the esophageal hiatus of the diaphragm between the cardia of the stomach and the liver. The **lesser omentum** is divided into a proximal and distal portion by the liver. The proximal portion reaches from the diaphragm to the liver and is referred to as the **hepatogastric ligament** (lig. hepatogastricum). The distal portion continues as the **falciforme ligament** (lig. falciforme) to the abdominal floor. The portion of the lesser omentum which expands from the duodenum to the liver is known as the **hepatoduodenal ligament** (lig. hepatoduodenale).

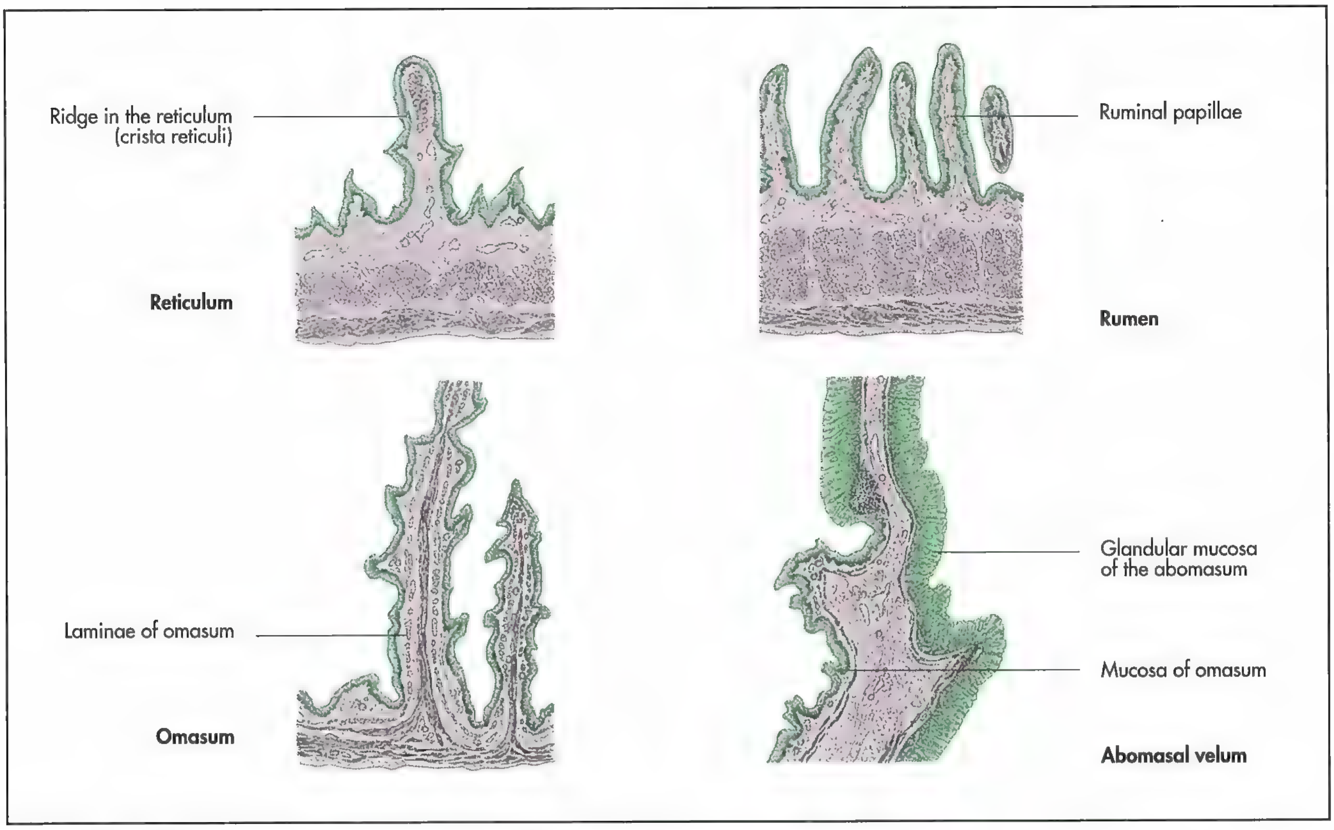

Fig 7-64. Walls of the different stomach compartments in the ox, schematic (Liebich, 2004).

The **common bile duct** (ductus choledochus) is enveloped in the hepatoduodenal ligament on its course from the liver to the duodenum, thus indicating the ontogenetic origin of this accessory gland of the digestive system. The duodenal ligament is the only remnant of the ventral mesentery present during embryonic development.

Complex stomach

The stomach of the domestic ruminants is composed of four chambers:

- Rumen,
- Reticulum,
- Omasum and
- Abomasum.

Rumen, reticulum and omasum are collectively referred to as **forestomach** (proventriculus), which has a **non-glandular mucosa** and is responsible for the enzymatic destruction of the complex carbohydrates, especially cellulose, which form a large part of the normal diet of ruminants and the production of short-chained fatty acids (propionate, butyrate and acetate) with the help of microbes.

The last chamber, the **abomasum** has a glandular mucosa and is comparable to the simple stomach of the other domestic mammals. A more detailed description of the function of the different chambers can be found in textbooks of veterinary physiology and nutrition.

All four chambers are derived from the **gastric spindle** during embryonic development without a contribution of the esophagus, which was hypothesised earlier due to the non-glandular lining of the proventriculus. The different chambers can be identified as expansions of the gastric spindle in the early embryo. They increase at unequal rates during embryonic and foetal development. At the time of birth the abomasum is the **largest part of the stomach,** which is appropriate since it is the only part, which has an immediate function to perform in receiving and digesting the milk, which bypasses the forestomach.

Although its form and structure is similar to that of an adults and the capacity already reaches 60% of an adult abomasum, it still takes a few days after birth for the mucosa to mature and function properly. This time window is very important to guarantee the resorption of colostral antibodies in the first 24 hours postpartum. After about three weeks, when the calf starts to eat solid food, the rumen and reticulum begin to show a rapid growth and by the eighth week they have almost overtaken the abomasum and by the twelfth week they are more than twice as large. At the same time the interior of the stomach changes: the reticulate pattern of the lining of the reticulum appears as well as the ruminal pillars. The definitive proportions and topography are established at 3 –12 months of age, depending on the diet.

The large stomach dominates the abdominal topography of ruminants by occupying almost the **whole of the left half of the abdomen** and a substantial part of the right half. The

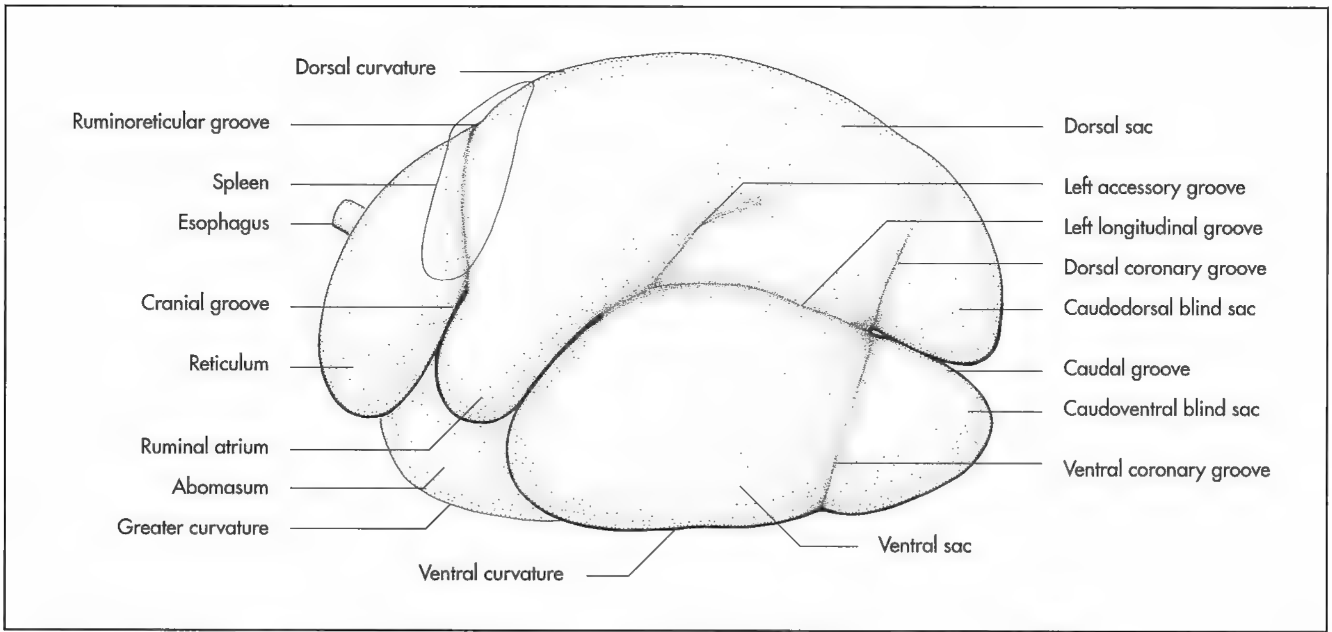

Fig 7-65. Compartments of the stomach of the ox, left lateral aspect, schematic (Schaller, 1992).

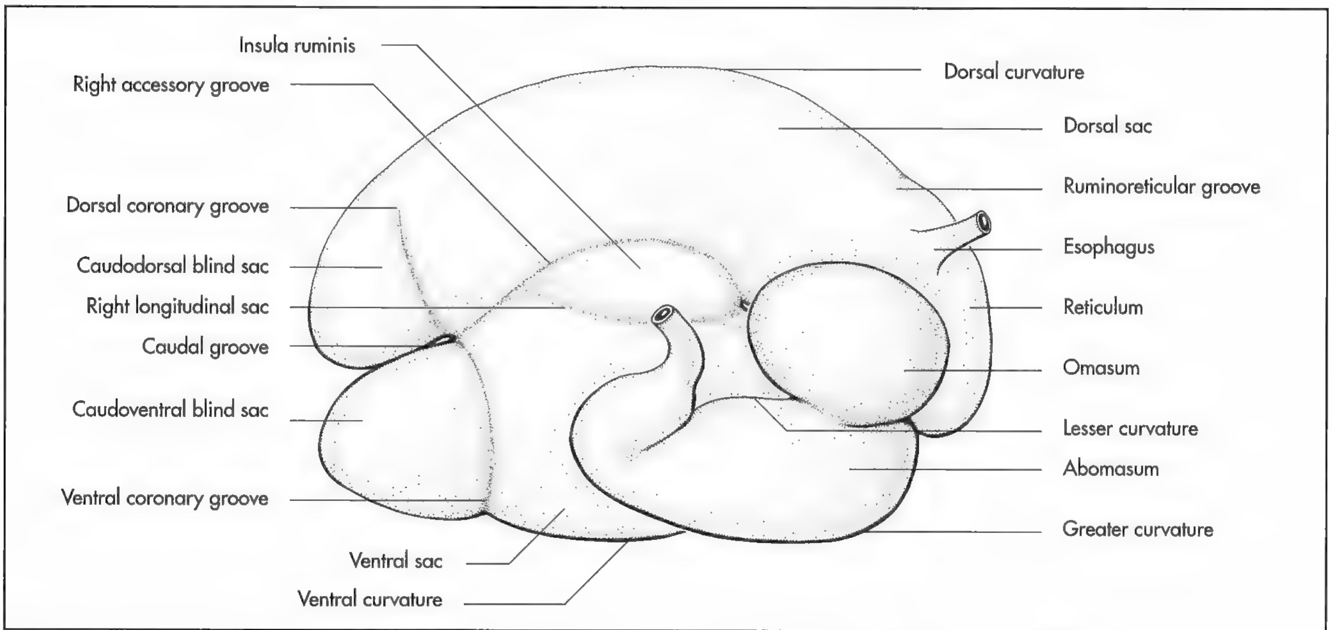

Fig 7-66. Compartments of the stomach of the ox, right lateral aspect, schematic (Schaller, 1992).

rumen is situated in the **left half of the abdomen,** the reticulum in the cranial part and the omasum in the right half. Its total capacity measures 60–100 l in adult cattle depending on the size of the animal, 80% of which is rumen alone.

Rumen and reticulum are so intimately related in structure and function that it is also referred to as **ruminoreticular compartment.** The division of the two is marked by an inflection of the wall, that projects internally, the **ruminoreticular fold** (plica ruminoreticularis).

Rumen

The rumen resembles a large, laterally compressed sac, which fills almost the entire left half of the abdomen and crosses the midline into the right half with its caudoventral portion. It extends from the diaphragm cranially to the pelvic inlet caudally. The rumen has a **parietal surface** (facies parietalis), adjacent to the diaphragm and the left lateral and ventral abdominal wall and a **visceral surface,** against the liver, the intestines, the omasum and the abomasum. These surfaces meet in the dorsal curvature, against the roof

Fig 7-67. Topography of the rumen in an ox. Parts of the lateral body wall, several ribs and the lateral ruminal wall are removed, left lateral aspect (Pavaux, 1983).

of the abdominal cavity and in the ventral curvature towards the floor of the abdominal cavity.

The rumen is divided into several portions by inflections of the walls, the **pillars of the rumen** (pilae ruminis), which project into the lumen. The ruminal portions (Fig. 7-65 to 67) are the:

- Ventral sac (saccus ventralis) with the ruminal recess (recessus ruminis),
- Dorsal sac (saccus dorsalis),
- Cranial sac (saccus cranialis, atrium ruminis),
- Caudodorsal blind sac (saccus caecus caudodorsalis),
- Caudoventral blind sac (saccus caecus caudoventralis).

These subdivisions are visible on the external surface as grooves, that correspond to the position of all these folds. The **principal ruminal pillars** (pila longitudinalis dextra et sinistra) encircle the whole organ, dividing it into dorsal and ventral **major sacs.** These are marked externally by the **left** and **right longitudinal grooves** (sulcus longitudinalis dexter et sinister) (Fig. 7-65, 66 and 68). The right longitudinal pillar (and the corresponding groove) splits into **two branches** (pilae accessoriae dextrae), which encircle an area of the right wall of the rumen, which is referred to as the **ruminal island** (insula ruminis) (Fig. 7-66). The two longitudinal grooves are connected cranially and caudally by deep **transverse grooves** (sulcus cranialis et caudalis). Lesser coronary pillars (pila coronaria dorsalis et ventralis) mark the **caudal blind sacs** and are visible as grooves on the external surface of the rumen (sulcus coronarius dorsalis et ventralis).

The most cranial part of the dorsal sac forms the **cranial sac** of the rumen, also called the **atrium** of the rumen, which has a wide communication with the reticulum through which food passes from the rumen into the reticulum and vice versa, thus playing an important role in remastication.

The division of the rumen from the reticulum is achieved by the **ruminoreticular fold** (plica ruminoreticularis) and is an inflection of the wall similar to the subdivisions of the rumen. The ventral ruminal sac is extended cranially to form the **ruminal recess** (Fig. 7-68).

The relative proportions of the compartments vary among the domestic ruminants. In the goat and sheep the dorsal sac is smaller than the ventral one, which has an extensive caudal projection.

The **non-glandular mucosa** of the rumen consists superficially of stratified, squamous epithelium and forms papillae, which gives the ruminal mucosa its characteristic appearance. The **ruminal papillae** are soft-tissue formations of the Lamina proper and submucosa are regarded to increase the epithelial surface area by a factor of seven (Fig. 7-69 and 70). This is important for the resorption of the volatile fatty acids produced by microbial fermentation, but also for the resorption of water, vitamins K and B. This function is facilitated by a very rich subepithelial vascular plexus.

The ruminal papillae are not developed over the centre of the roof or the free margins of the pillars. Individual papillae show a great variation in form and size: they vary from low round elevations through conical and tonguelike forms to flattened leaves. Prominence, form and density largely depends on the diet the animal is fed on. Increasing the amount of rough

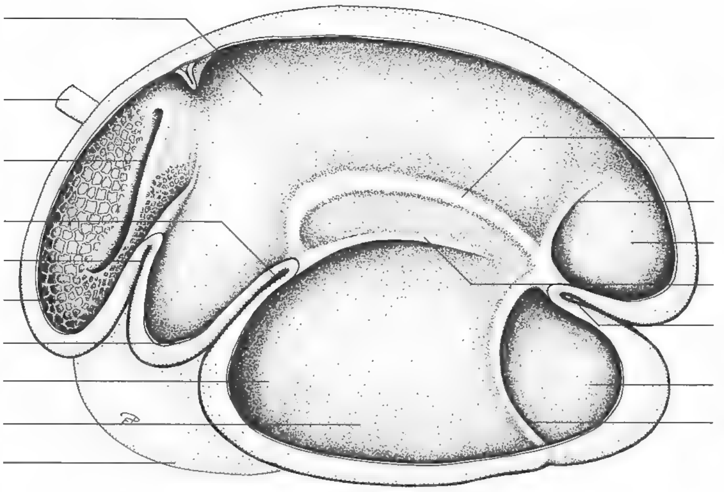

Fig 7-68. Interior of the rumen of the ox, left aspect, schematic (Schaller, 1992).

food results in shortening of the papillae whereas increasing the energy content of the diet causes the papillae to become longer as seen in cows during lactation. Similar adaptive mechanisms are also seen in wild ruminants, in which proliferation and regression of the papillae depend on the season (winter versus summer, raining season versus drought).

Reticulum

The reticulum is intimately related to the rumen in structure and function and many authors refer to describe a combined ruminoreticular compartment (Fig. 7-65, 71 and 72). The spherical reticulum is much smaller than the rumen and is located just cranial to the latter in contact with the caudal surface of the diaphragm. It lies just ventral to the esophageal-gastric junction and above the xiphoid process of the sternum. This position allows the application of external pressure to elicit pain if the reticulum is diseased. Cattle are non-selective feeders and often ingest foreign bodies, such as nails or pieces of wires, with their forage. Due to their weight these bodies tend to collect within the reticulum and may be driven trough the reticular wall by the contractions of this

Fig 7-69. Ruminal papillae of the caudodorsal blind sac of an ox.

Fig 70. Close-up view of ruminal papillae on the caudodventral sac of an ox.

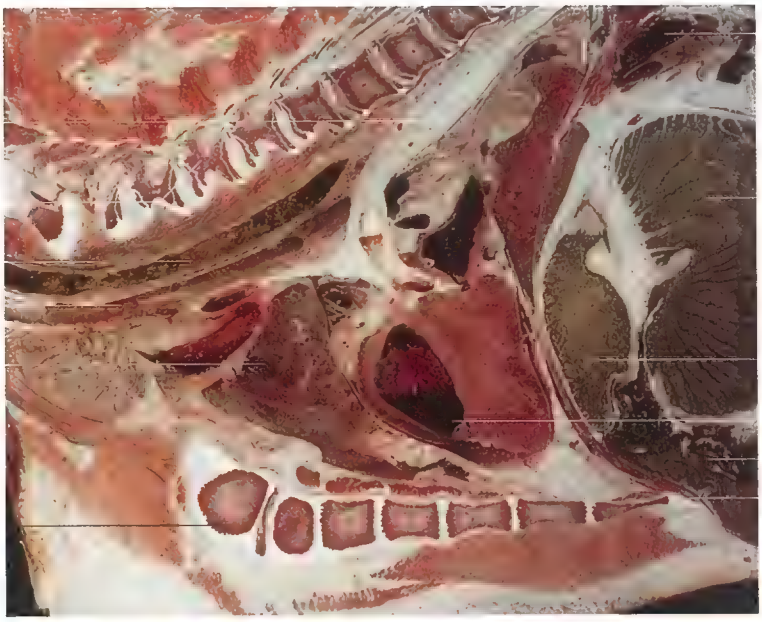

Fig 7-71. Paramedian section of the cranial part of a bovine trunk, demonstrating the close relationship between the heart and the reticulum.

Fig 7-72. Interior of a bovine reticulum.

organ (traumatic reticulitis-"hardware disease"). Common sequelae include purulent pericarditis after penetration of the diaphragm or abscessation of the liver and other adjacent tissues (Fig. 7-71).

The **reticular mucosa** is non-glandular and lined by a stratified epithelium, similar to the ruminal mucosa. It has a distinctive honeycomb pattern formed by **ridges** (crista reticuli), that outline 4-, 5- and 6-sided **cells** (cellulae reticuli) (Fig. 7-64 and 72). These ridges and the cell floors between them carry short papillae.

The smooth muscle of the ruminoreticular wall is arranged in two layers, an outer thinner layer and an thicker inner layer, the fibres of which are orientated in a more or less perpendicular angle to each other. The regular sequence of ruminoreticular contractions mixes and redistributes the stomach contents and plays an important role in regurgitation of the food for remastication.

Omasum

The omasum lies within the intrathoracic part of the abdomen to the right of the ruminoreticular compartment (Fig. 7-66). It has the shape of a bilaterally flattened sphere in cattle and is bean-shaped in the goat and sheep. It communicates with the

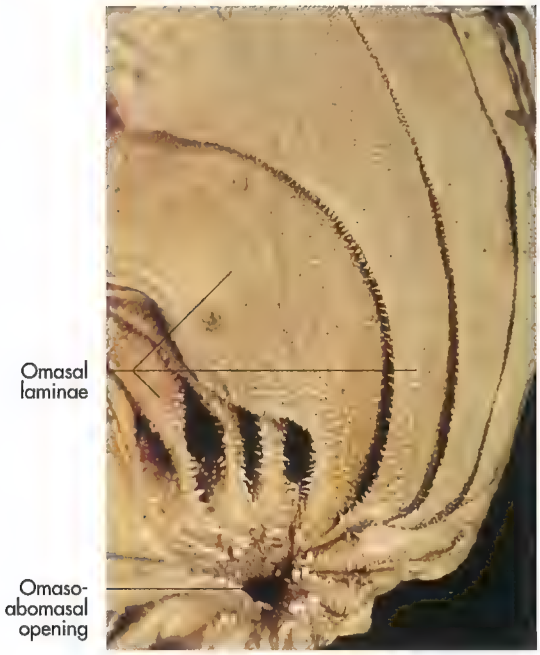

Fig 7-73. Bovine omasum.

Fig 7-74. Section of a bovine omasum.

Fig 7-75. Histological section of a bovine omasum.

reticulum through the **reticulo-omasal opening** (ostium reticulo-omasicum) and with the abomasum through the large, oval omaso-abomasal opening. The **omaso-abomasal opening** is flanked by two mucosal **folds** (vela abomasica), which are thought to be able to close this opening to prevent reflux of the ingesta from the abomasum into the omasum.

The two openings are connected by the **omasal groove** (sulcus omasi). The interior is occupied by a multitude of **parallel laminae** (laminae omasi), that arise from the roof and the sides and project towards the floor, but leave room for the omasal canal, the floor of which is the omasal groove. The crescentic laminae are of different lengths and sizes and divide the lumen into a series of narrow recesses (Fig. 7-73, 74 and 75). The laminae are thin muscular sheets covered with a non-glandular mucosa, which forms short papillae. Omasal contractions are biphasic. The first phase presses food from the omasal canal into the omasal recesses, where resorption of water takes place. The second phase discharges the now dryer contents of the omasal recesses into the abomasum.

An unbalanced diet can result in impaction of the omasum, which is fatal in most cases. On postmortem examination the characteristic findings include a very hard omasum, packed with dry contents.

Abomasum

The abomasum corresponds to the simple stomach of the other domestic mammals (Fig. 7-66 and 77) and analogous to that it can be divided into **fundus, body** and **pylorus.** It has a greater curvature facing ventrally and a minor curvature facing dorsally. It is lined by a glandular mucosa, which contains **gastric glands proper** and **pyloric glands.** During the suckling period rennet is produced, which is essential for the digestion of milk. The mucosal surface area is increased by the presence of large **folds** (plicae spirales), which have a spiral orientation and do not disappear when the stomach distends. The musculature comprises an outer longitudinal layer and an inner circular layer.

The position and relationship of the abomasum is rather variable and depend upon the fullness of the forestomach and their activities. Age and pregnancy are other factors influencing its topography. Although there are limits to the normal variations beyond which deviations produce digestive disturbance and may be endanger life. Abomasal displacement, to the left or right, is a well recognised disorder especially in dairy cows.

Gastric groove (sulcus ventriculi)

The gastric groove consists of the reticular groove extending in the ruminoreticular compartment, the omasal groove in the omasum and the abomasal groove in the abomasum. The reticular groove extends from the esophagus (Fig. 7-68), which joins the forestomach at the junction of the rumen and reticulum, to the omasum, where it continues as the omasal canal to the abomasum. It is bounded by spiral muscular lips, which reflexly contract in unweaned animals stimulated by sucking from the dam to convert the groove into a closed tube, which channels the milk directly into the abomasum.

With continuing growth and change of diet and feeding regimes this bypass is used less frequently. Closure of the groove can be stimulated by certain chemicals, such as copper sulphate, which may be useful when application of

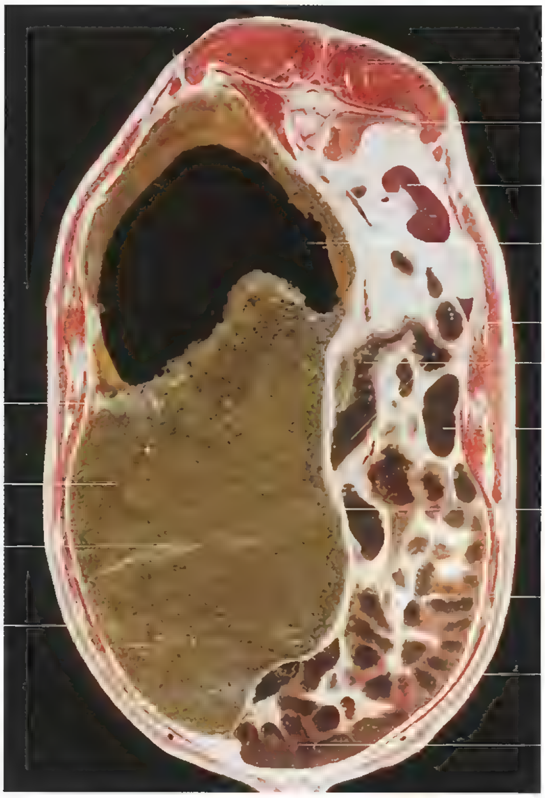

Fig 7-76. Transverse section of a bovine abdomen at the level of the third lumbar vertebra, caudal aspect.

drugs to the abomasum is desirable. A fold-free band along the lesser curvature of the abomasum is considered to be the third part of the gastric groove.

Omenta

Analogous to the simple stomach of the other domestic mammals the omenta are derivatives of the **dorsal** and **ventral mesogastrium.** To understand the rather complex topography of the omenta it is helpful to remember that the three compartments of the forestomach and the abomasum develop as expansions of the gastric spindle in the early embryo. The gastric spindle is suspended from the roof of the abdominal cavity of the embryo by the dorsal mesogastrium and attached to the floor of the abdominal cavity by the ventral mesogastrium. The rumen, reticulum and most of the abomasum develop from the **greater curvature,** the omasum and a smaller part of the abomasum from the **lesser curvature.** Consequently the **greater omentum** attaches to the rumen, the reticulum and to the abomasum (Fig. 7-77). The attachment begins dorsal to the esophagus, pass caudally along the right longitudinal groove through the caudal groove and cranially again along the left longitudinal groove. It crosses the atrium ruminis and widens to form a broad attachment to the reticulum before bending sharply to the right, ventral to the ruminoreticulum to reach the greater curvature of the abomasum. It follows the greater curvature to the pylorus where it passes onto the mesoduodenum. The dorsal sac of the rumen lies in direct contact with the dorsal abdominal wall and the diaphragmatic crura. Thus it has a retroperitoneal position and does not have a dorsal mesentery.

The **lesser omentum** arises from the visceral surface of the liver, between the portal vein and the esophageal impression, passes onto the right surface of the omasum, the lesser curvature of the abomasum and onto the duodenum. Similar to the lesser omentum in the other domestic mammals it can be divided into the hepatogastric and the hepatoduodenal ligament.

The omental sheets enclose the **omental bursa,** a capillary cleft, which is completely divided from the rest of the abdominal cavity, except at the epiploic foramen. The **epiploic foramen** is situated between the liver and the duodenum, between the caudal vena cava dorsally and the portal vein ventrally. The walls of the bursa are formed by the visceral and parietal sheets of the omenta similar to the situation described in the dog, with the exception that the right lateral border blends with the mesoduodenum, whereas on the left there is no direct communication between the two layers, but the rumen is interposed. Thus the deep sheet attaches to the right longitudinal groove and the superficial sheet to the left longitudinal groove of the rumen, the two meet in the caudal ruminal groove. The omasum, abomasum and lesser omentum provide most of the cranial bursal wall.

The intestines are located in the space above the omental bursa and to the right of the rumen, which is known as the **supraomental recess** (recessus supraomentalis). It is open caudally and often entered by the pregnant uterus (Fig. 7-76). If the abdominal cavity is entered through an incision on the

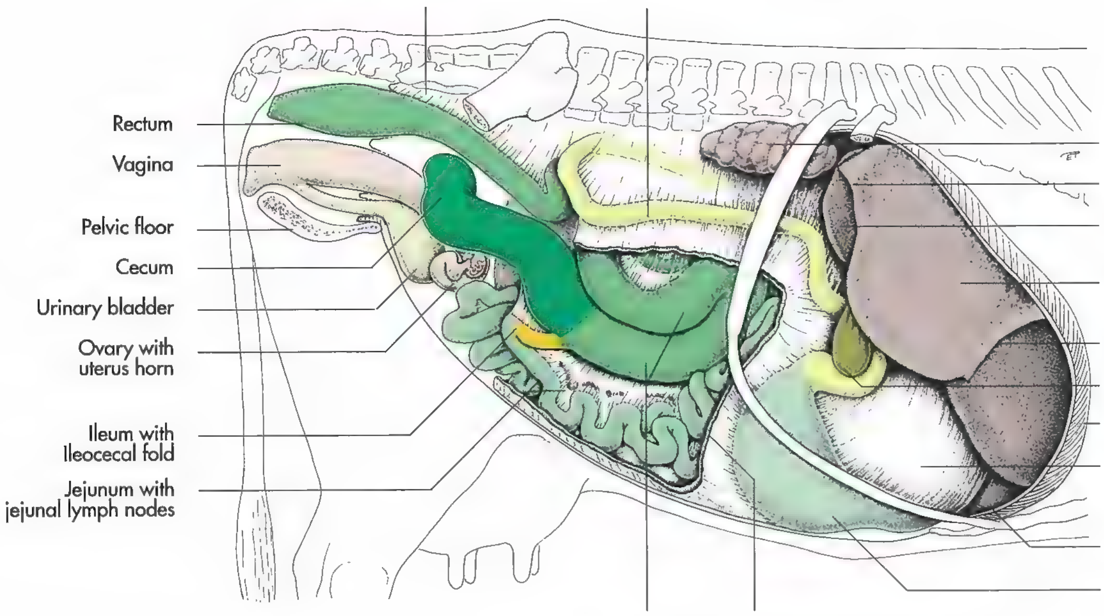

Fig 7-77. Topography of the abdominal and pelvic organs of the ox, right lateral aspect, abdominal wall and greater omentum removed, schematic.

right flank, the descending duodenum is usually the only part of the gastrointestinal tract visible. The rest is covered by the mesoduodenum and the superficial wall of the greater omentum. Incising the latter leads into the omental bursa and exposes the deep wall of the greater omentum, which covers the intestines within the supraomental recess.

The **greater omentum** is an important store of fat, which usually renders the omentum opaque.

Blood supply

Similar to the simple stomach of the other domestic mammals, the **stomach of ruminants** is supplied by several branches of the **celiac artery.** In addition to the three main branches of the celiac artery present in animals with a simple stomach (a. lienalis, a. gastrica sinistra, a. hepatica), there is a **left** and **right ruminal artery** (a. ruminalis dextra et sinistra). The large right ruminal artery runs caudally in the right longitudinal groove and continues into the left longitudinal groove by passing between the dorsal and ventral blind sacs. It ends in an anastomosis with the left ruminal artery, which follows the cranial groove between the atrium and the ventral sac and caudally in the left longitudinalgroove. Shortly after its origin the left ruminal artery extends the reticular artery to supply the reticulum.

The **omasum** and **abomasum** are supplied by the **gastric** and **gastroepiploic arteries.** The left gastric artery is a direct branch of the celiac artery and passes on the right side of the rumen to the lesser curvature of the abomasum where it eventually unites with the right gastric artery, which is a branch of the hepatic artery. The left gastroepiploic artery leaves the left gastric artery at the level of the omasum and runs to the greater curvature of the abomasum. Here it anastomoses with the right gastroepiploic artery coming from the hepatic artery.

Thus, the abomasum is supplied by a **double perigastric ring of arteries,** which provide a direct connection between the hepatic and the left gastric artery. The gastric artery also extends branches to the omasum. The **veins** are satellite to the arteries and ultimately join the portal vein.

Innervation

Gastric innervation is achieved by **sympathetic** and **parasympathetic nerves.** The sympathetic fibres come from the celiac plexus and form the gastric plexus and the right and left ruminal plexus. The latter also detaches branches to the reticulum and the spleen.

Parasympathetic fibres arise from the **vagus nerve.** The dorsal vagal trunk is extensively connected with the celiac plexus, but also supplies direct branches to the rumen, the left and right ruminal branches (ramus ruminalis dexter and sinister). Additional branches innervate the reticulum, the atrium ruminis, the omasum, the abomasum and the gastric groove.

The ventral vagal trunk detaches branches to the atrium ruminis, reticulum, gastric groove, the lesser curvature of the abomasum and the pylorus. Additional branches extend to the liver and the duodenum.

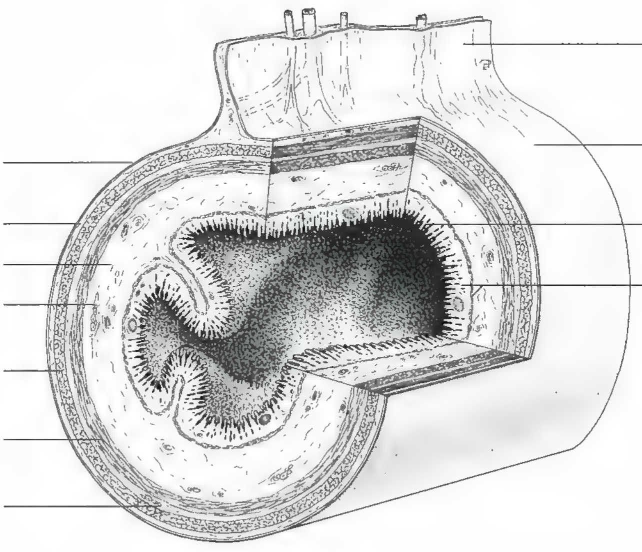

Fig 7-78. Transverse section through the intestine with mesentery, schematic.

Lymph nodes

Lymphatic drainage of the ruminal stomach is achieved by many smaller lymph nodes, which are scattered over the ruminal stomach, particularly in the ruminal grooves and omasal and abomasal curvatures. They belong to the **celiac group of lymph nodes (lymphocentre).** After passage through these lymph nodes, the lymph leads to a number of large atrial (splenic) lymph nodes between the spleen and the cardia. The lymph nodes along the curvature of the stomach direct their efferent vessels to the hepatic lymph nodes. The following groups of lymph nodes can be distinguished:

- **Left** and **right ruminal lymph nodes** (lnn. ruminales dextri et sinistri) in the left and right longitudinal ruminal groove,
- **Cranial ruminal lymph nodes** (lnn. ruminales craniales) in the cranial ruminal groove,
- **Reticular lymph nodes** (lnn. reticulares) on the dorsal and ruminal surface of the reticulum,
- **Omasial lymph nodes** (lnn. omasiales) on the greater curvature of the omasum,
- **Rumino-abomasial lymph nodes** (lnn. ruminoabomasiales) between the atrium ruminis, reticulum and abomasum,
- **Dorsal abomasial lymph nodes** (lnn. abomasiales dorsales) on the lesser curvature of the abomasum,
- **Ventral abomasial lymph nodes** (lnn. abomasiales ventrales) are inconsistent on the greater curvature of the abomasum.

Intestine

The intestine is the caudal part of the alimentary canal. It commences at the pylorus and continues to the anus. It is divided into the **small intestine** (intestinum tenue) from the pylorus to the cecum and the **large intestine** (intestinum crassum) from the cecum to the anus. The diameter of these parts do not allways differ, as their names would suggest (Fig. 7-85 to 88).

The **small intestine** comprises three parts:
- the duodenum,
- the jejunum and
- the ileum.

The **large intestine** consists of:
- the blind-ending cecum,
- the colon and
- the rectum (Fig. 7-85 to 88).

The total length of the intestine differs between species, breeds and even individuals. It is rather difficult to assess intestinal length in the living animal. Post mortem and cessation of peristaltic contractions, the intestine increase in length. As a result of gastrointestinal adaption to the different diets and feeding habits the intestinal tract of carnivores is rather short compared to the long intestines in herbivores. Generally the length of the intestine is considered to be five times the body length in carnivores, ten times the body length in the horse and 20 to 25 times the body length in ruminants.

Structure of the intestinal wall

The intestine like the other parts of the alimentary canal is composed of several layers (from the inside to the outside) (Fig. 7-78 to 80):

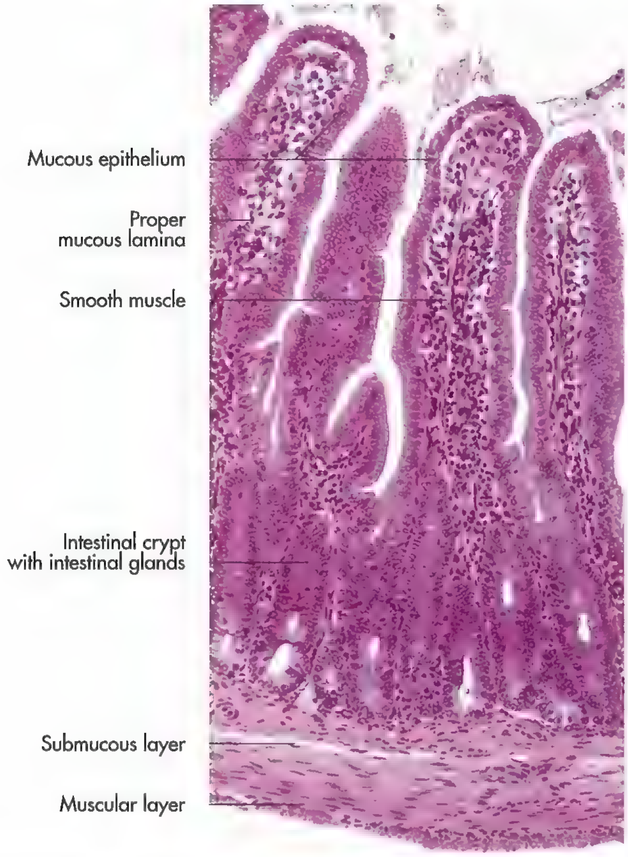

Fig 7-79. Histological section of the jejunal wall of a cat, demonstrating intestinal villi and crypts.

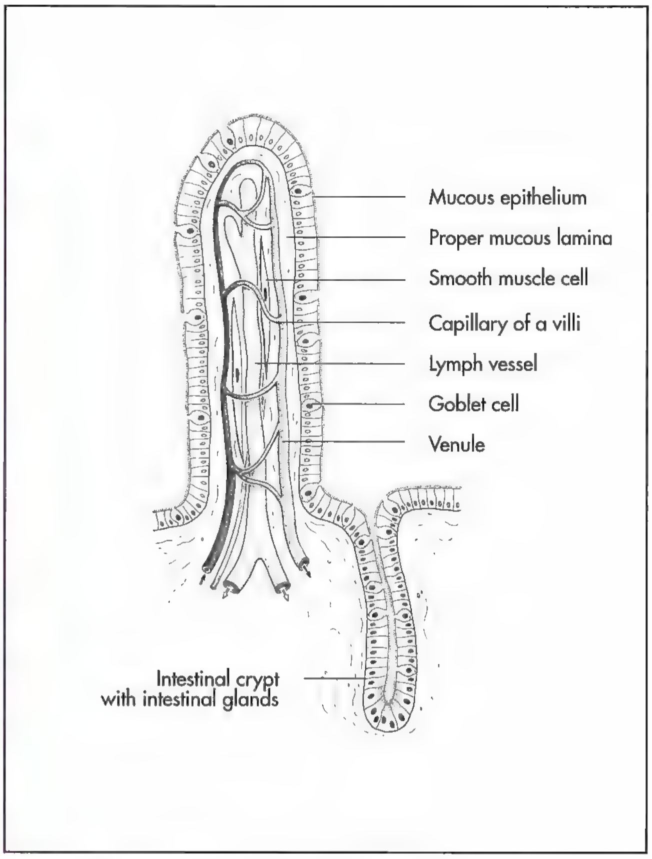

Fig 7-80. Intestinal villi and crypts, schematic.

- Mucosa (tunica mucosa),
- Submucosa (tela submucosa),
- Muscular layer (tunica muscularis) and
- Peritoneum (serosa seu lamina visceralis).

The single layered **epithelium of the mucosa** consists of **columnar cells,** which function in absorption and interspersed goblet cells that produce mucous. Throughout the alimentary canal the propria mucosa is occupied largely by the straight, tubular **intestinal glands** (glandulae intestinales) (Fig. 7-79 and 80). In the small intestine the surface of the mucosa is considerably increased by the presence of innumerable **intestinal villi** (villi intestinales). These densely packed, finger-like projections give the luminal surface of the small intestine its characteristic velvety look. The increase in surface area that this provides is essential for the absorptive functions of this part of the gastrointestinal tracpt.

Microscopic **intestinal glands** (crypts) open to the surface between the bases of villi. Absorption is facilitated by the fact, that each villus has its own arteriole which resolves in a capillary net at the free end of the villus, which in turn, drains into a venule at the base of the vilus. This microsystem is complemented by lymphatic capillaries, which drain the products of fat digestion.

The **mucosa of the large intestine** differs from that of the small intestine, in that there are **no intestinal villi.** The intestinal glands of the large intestine are longer, straighter and richer in goblet cells, which produce the mucus necessary to ensure a smooth passage of the gut contents. Its most important function is the re-absorption of water and thus the dehydration of its fecal contents. In the horse, however many absorption mechanisms are located in the large bowel. Further details can be found in histology and physiology textbooks. Similar to the stomach the capillaries are arranged to form a subepitheliar honeycomb shaped network.

The **lymphatic tissue** of the intestinal wall is the first line of defence against microorganisms, which may gain access to the body from the intestines. It is present as scattered lymphocytes in the mucosa, forms **single follicles** (lymphonoduli solitarii) or may aggregate to form **Peyer-patches.**

Peyer's patches are visible on the free surface of the mucosa as irregularly raised plaques or bands, ranging in length from a few millimetres to more than 25 cm in the ox. These are particularly well developed in the ileum and extend into the large bowel of the horse and ruminants. In the pig these patches are found in the jejunum and in the ileum. In the cat lymph follicles are especially numerous in the apex of the cecum.

The **submucosa** consists of loose connective tissue with smaller blood vessels, lymphatics, lymph follicles and nerve plexus located in it. In addition to the intestinal glands of the mucosa, tubular duodenal glands are found in the submucosa of the proximal part of the small intestine. The submucous nerve

plexus are also known as the Meissner's plexus and supply the intramural glands, smooth muscle fibres and vessel walls.

The **muscular layer** (tunica muscularis) consists of a relatively thin outer longitudinal layer and a thicker inner circular layer. At the anus the circular layer is modified to form the **internal anal sphincter** (m. sphincter ani internus). In the horse and the pig the outer muscular layer is mainly concentrated in a number of bands **(taenia).** Shortening of these taenia results in the formation of linear sacculations **(haustra).**

The **serosal layer** of the intestine is provided by the visceral part of the peritoneum. Extending from the dorsal body wall the double sheets of the **connecting serosa (mesentery)** separate to cover the intestine. The mesentery serves as route for blood vessels and nerves and contains lymph nodes.

The **lymph vessels** from the intestines drain into the following lymph nodes: portal lymph nodes, pancreaticoduodenal lymph nodes, cranial mesenteric lymphnodes, cecal lymph nodes, jejunal lymph nodes, colic lymph nodes, anorectal lymph nodes.

Innervation of the intestine

The intestine receives both, sympathetic and parasympathetic nerves. The nervous system of the intestine comprise a complex system of intramural ganglia, which form plexus in the different layers of the intestinal wall. The submucosa contains the **submucosual nerve plexus (Meissner-plexus)** and another plexus is located between the two layers of the **muscular layer (Auerbach-plexus)** (Fig. 7-78). Both plexi are connected to the prevertebral ganglia of the abdominal cavity by a fine subserous network of nerve fibres. These plexi are under the control of the parasympathetic and the sympathetic systems, however they are act independently and are responsible for the apparently spontaneous muscular and secretory activity of the gut.

Blood supply of the intestine

The blood supply to the intestines is mainly provided by the **cranial** and **caudal mesenteric arteries** (a. mesenterica cranialis et caudalis) (Fig. 7-85 to 88 and Fig. 12-35), with the exception of the proximal part of the duodenum, which is supplied by the hepatic branch of the **celiac artery** (a. coeliaca) and the caudal part of the rectum, which is supplied by the rectal branches of the internal pudendal artery (a. pudenda interna). Although the details of branching vary between species and even individuals, the cranial mesenteric artery divides into three main branches:

- Jejunal artery (a. jejunalis),
- Ileocolic artery (a. ileocolica),
- Middle colic artery (a. colica media).

The **trunk of the jejunal artery** passes to the left and divides into numerous jejunal arteries, which run in the mesentery towards the jejunum. Shortly before reaching the jejunum they anastomose with each other forming arcades. From these arcades branches are detached to the mesenteric surface of the jejunal wall. The richness of anastomoses ensures that the intestine will normally survive the complete obstruction of one of the jejunal vessel. The first jejunal artery detaches the caudal pancreaticoduodenal artery, the last of the jejunal arteries anastomoses with the mesenterial ileal branch of the ileocolic artery.

After originating from the cranial mesenteric artery the **ileocolic artery** passes to the left and supplies the ileum, cecum and the ascending colon with the following branches:

- Mesenteric and antimesenteric ileal branch (ramus ilei mesenterialis et antimesenterialis) of the ileum,
- Lateral and medial cecal artery (a. caecalis lateralis et medialis) of the cecum,
- Colic branch (ramus colicus) of the proximal part of the ascending colon and
- Right colic artery (a. colica dextra) of the distal part of the ascending colon.

In the horse the right colic artery supplies the dorsal part of the colon and is therefore referred to as **dorsal colic artery** (a. colica dorsalis), while the blood supply of the ventral colon is provided by the colic branch, which is referred to as **ventral colic artery** (a. colica ventralis). The two colic arteries form an anastomosis at the pelvic flexure of the colon.

The middle colic artery is the third branch of the cranial mesenteric artery and provides the blood supply for the transverse colon. It anastomoses with the ileocolic artery via the right colic artery and with the caudal mesenteric artery via the left colic artery.

Not only does the cranial mesenteric artery provide the blood supply for a large part of the intestine it also has an important function in supporting the intestine. The soft-tissue connection of the aorta to the spine by the adventitia provides a form of suspension from the dorsal body wall to the cranial mesenteric artery. At the same time the blood pressure within the intestinal arteries render these quite inflexible, similar to a garden hose under pressure, which provides an additional means of fixation for the abdominal organs. This is a particularly important mechanism in the horse, in which the intestine is very mobile due to its relatively long mesentery. It is hypothesised that a change in blood pressure, e.g. by parasitic infestation of the arterial walls can lead to intestinal displacement and thus cause colic in the horse.

The smaller **caudal mesenteric artery** originates from the abdominal aorta shortly before it reaches its terminal branch. Its distribution is restricted to the descending colon and the proximal part of the rectum. It divides into the **left colic artery** (a. colica sinistra) and the **cranial rectal artery** (a. rectalis cranialis). The left colic artery passes cranially within the mesentery of the descending colon and detaches small branches to the mesenterial surface of the descending colon. The cranial rectal artery supplies the cranial part of the rectum.

The **veins** are mainly parallel to the arteries and join to form the **cranial** and **caudal mesenteric veins.** These veins are two of the main supplies of the **portal vein** with the splenic vein being the third. The veins of the caudal part of the rectum and the anal region join the **caudal vena cava.**

The **portal vein** receives the venous blood from the distribution of the celiac, cranial and caudal mesenteric arteries. Thus, it collects the venous blood from all **unpaired abdominal organs** except for the terminal rectum.

Fig 7-81. Transverse section of a feline abdomen, caudal aspect (König, 1992).

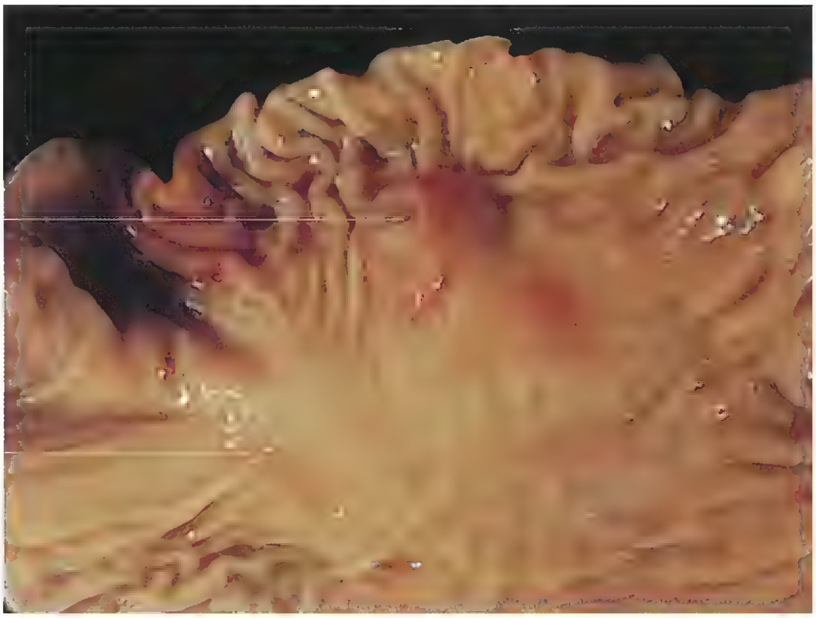

Fig 7-82. Luminal surface of the duodenal mucosa of a horse.

Small intestine (intestinum tenue)

The main functions of the small intestine are digestion and absorption. Digestion is defined as the enzymatic destruction of ingested material into particles ready for absorption. Both, the pancreatic and the bile ducts open into the small intestine: pancreas secretion is the major source of the enzymes and the bile is responsible for the emulsification of fat essential for digestion.

The **mucosal epithelium** consists mainly of columnar cells, which function in absorption, mucus-production and endocrine function, which control pancreatic secretion and muscular function of the gallbladder and the intestinal walls (Fig. 7-79 and 80). The mucosa is rich in lymphoid follicles, which aggregate to form **Peyer-patches** (Fig. 7-84). The small intestine begins at the pylorus and ends at the cecocolic junction. It consists of three main parts (Fig. 7-85 to 88):

- Duodenum,
- Jejunum,
- Ileum.

The **small intestine** is connected to the dorsal abdominal wall by the **dorsal mesentery** over its whole length. The mesentery is **relatively long** for the most part and allows a great degree of mobility to the small intestine. However in the horse and in ruminants the duodenum is fixed in its position by a **short mesoduodenum.**

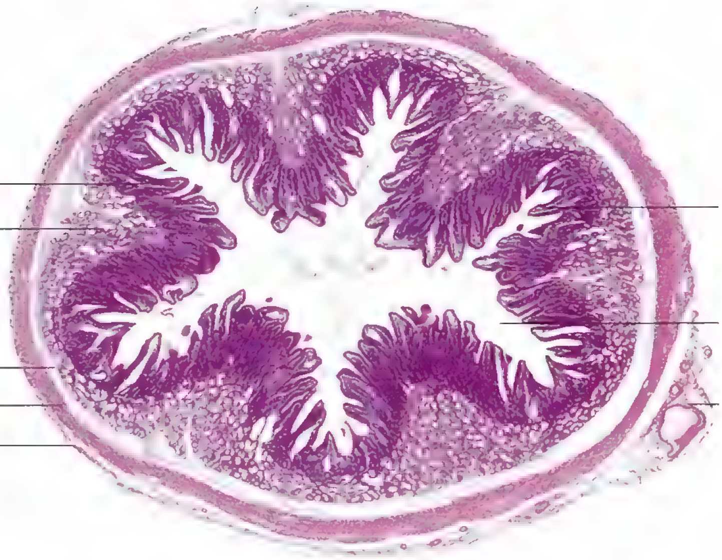

Fig 7-83. Histological section of the duodenum of a cat (Liebich, 2004).

Fig 7-84. Histological section of the ileum of a dog.

Duodenum

The duodenum is the proximal part of the small intestine, extending from the pyloric part of the stomach to the jejunum (Fig. 7-85 to 88).The duodenum can be subdivided into:

- Cranial portion (pars cranialis duodeni),
- Cranial duodenal flexure (flexura duodeni cranialis),
- Descending portion (pars descendens duodeni),
- Caudal duodenal flexure (flexura duodeni caudalis), also known as transverse portion (pars transversa),
- Ascending portion (pars ascendens) and
- Duodenal jejunal flexure (flexura duodenojejunalis).

The initial portion continues from the pylorus of the stomach and passes toward the right abdominal wall before deflecting caudally to descend to the pelvic inlet. It then passes medially around the cranial root of the mesentery before ascending cranially for a short distance. It ends by bending ventrally, where it is continued as the jejunum.

Unlike in humans where the extent of the duodenum is defined over the presence of the duodenal glands, the caudal end of the duodenum is marked by the cranial border of the **duodenocolic fold** (plica duodenocolica) (Fig. 7-85 to 88). The duodenum is attached to the abdominal roof by the mesoduodenum, the cranial part of the mesentery, which is relatively short in the horse and in ruminants, but longer in carnivores and the pig (Fig. 7-85 to 88). The long mesoduodenum together with the rath-

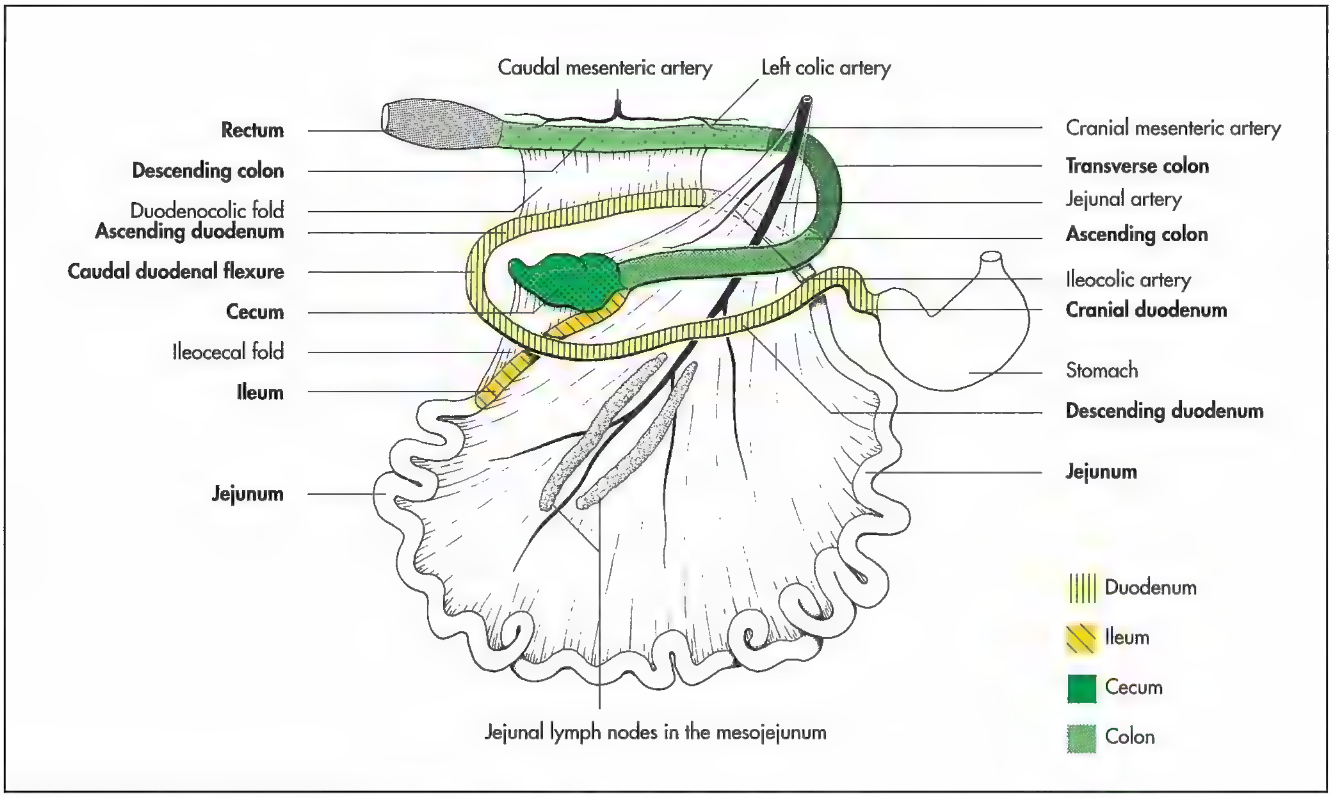

Fig 7-85. Intestinal tract of the dog, schematic (Ghetie, 1958).

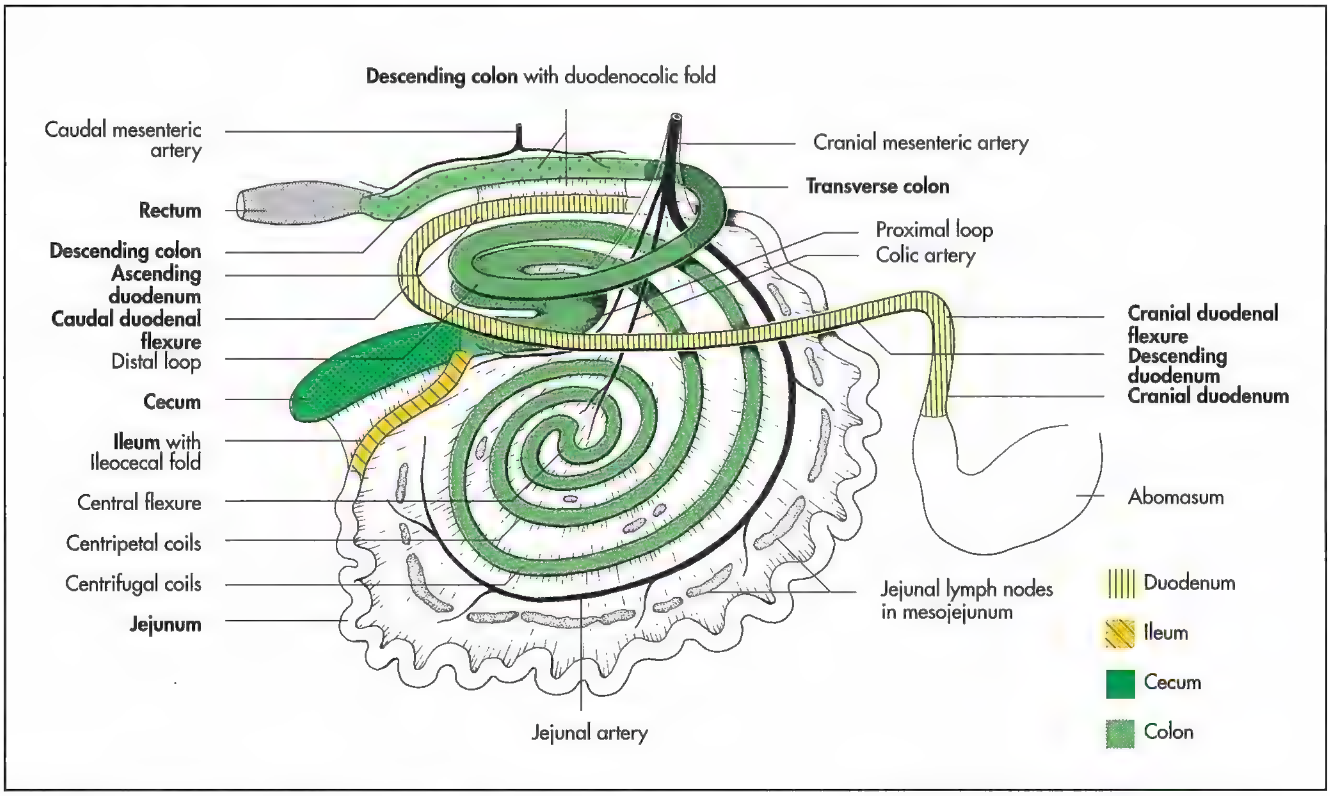

Fig 7-86. Intestinal tract of the ox, schematic (Ghetie, 1958).

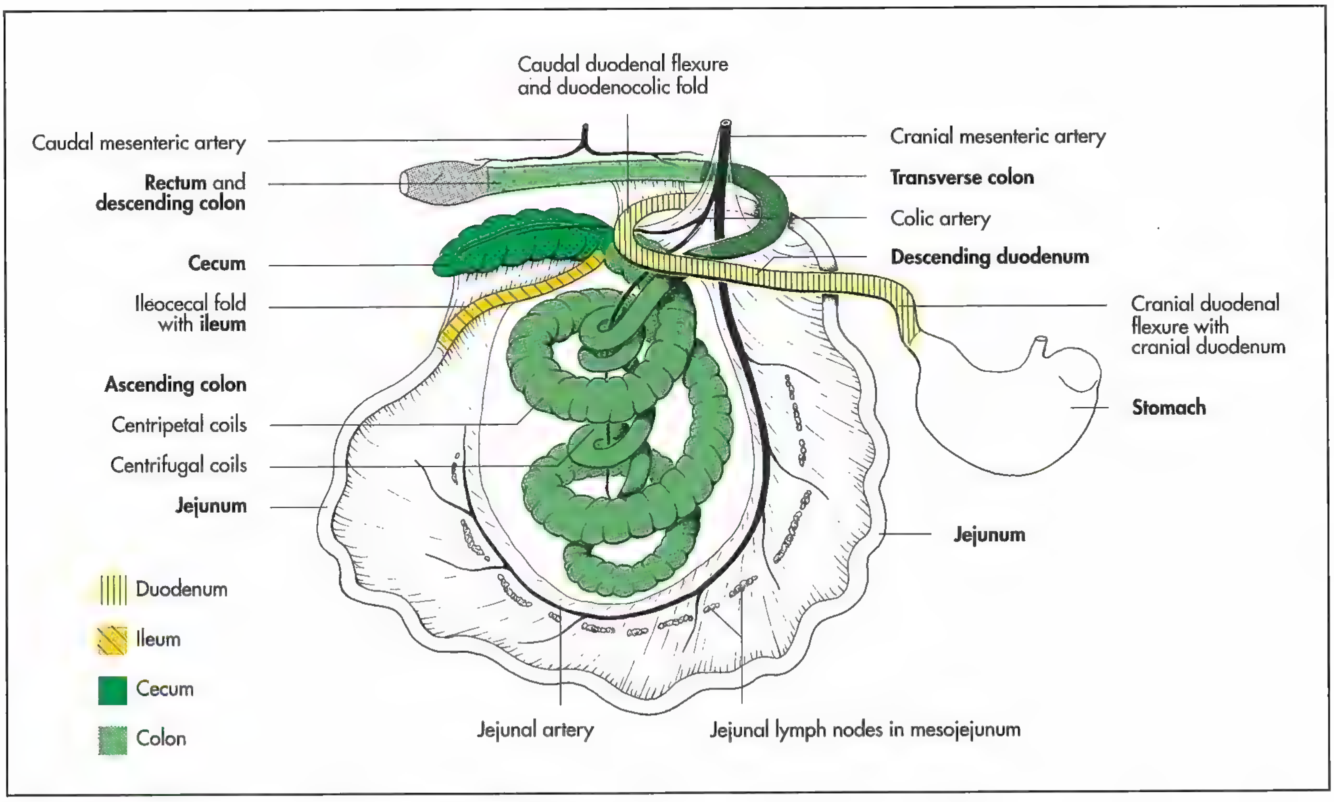

Fig 7-87. Intestinal tract of the pig, schematic (Ghetie, 1958).

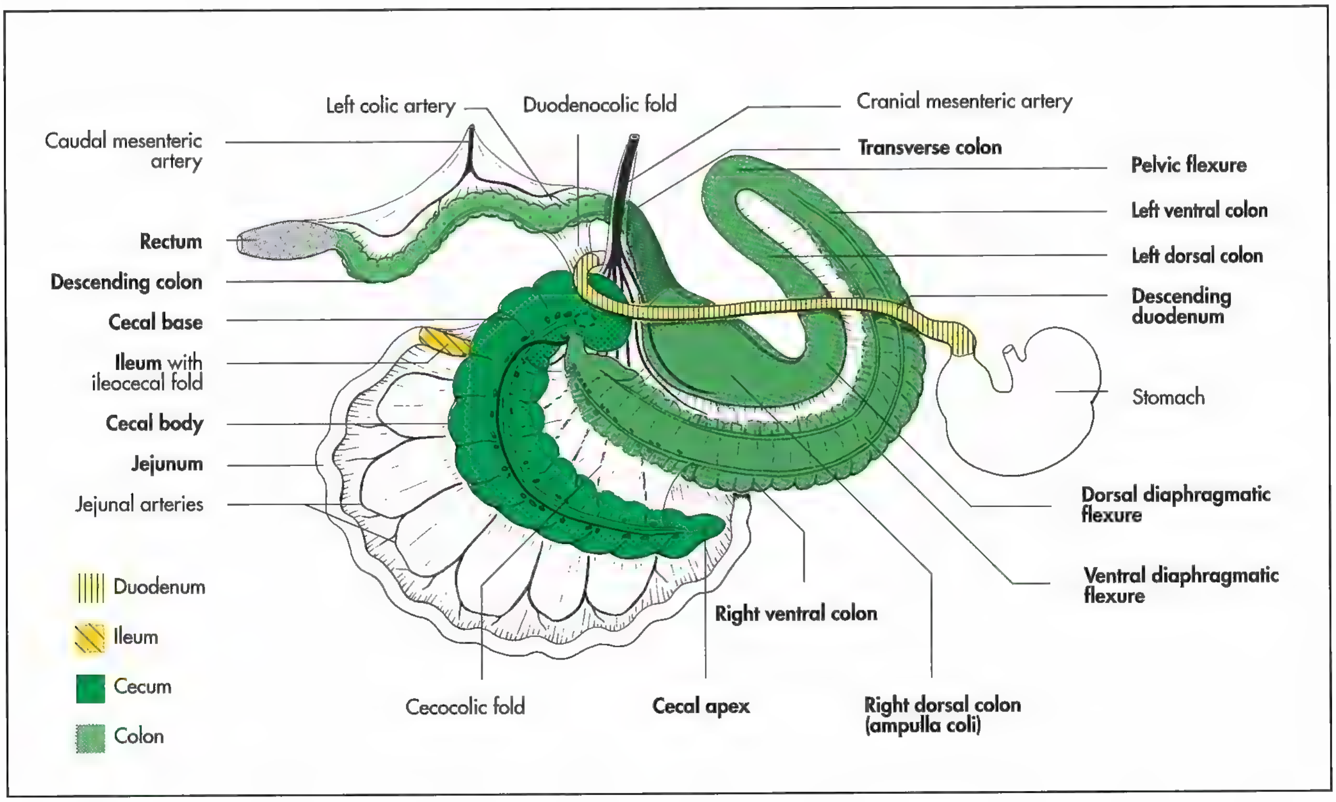

Fig 7-88. Intestinal tract of the horse, schematic (Ghetie, 1958).

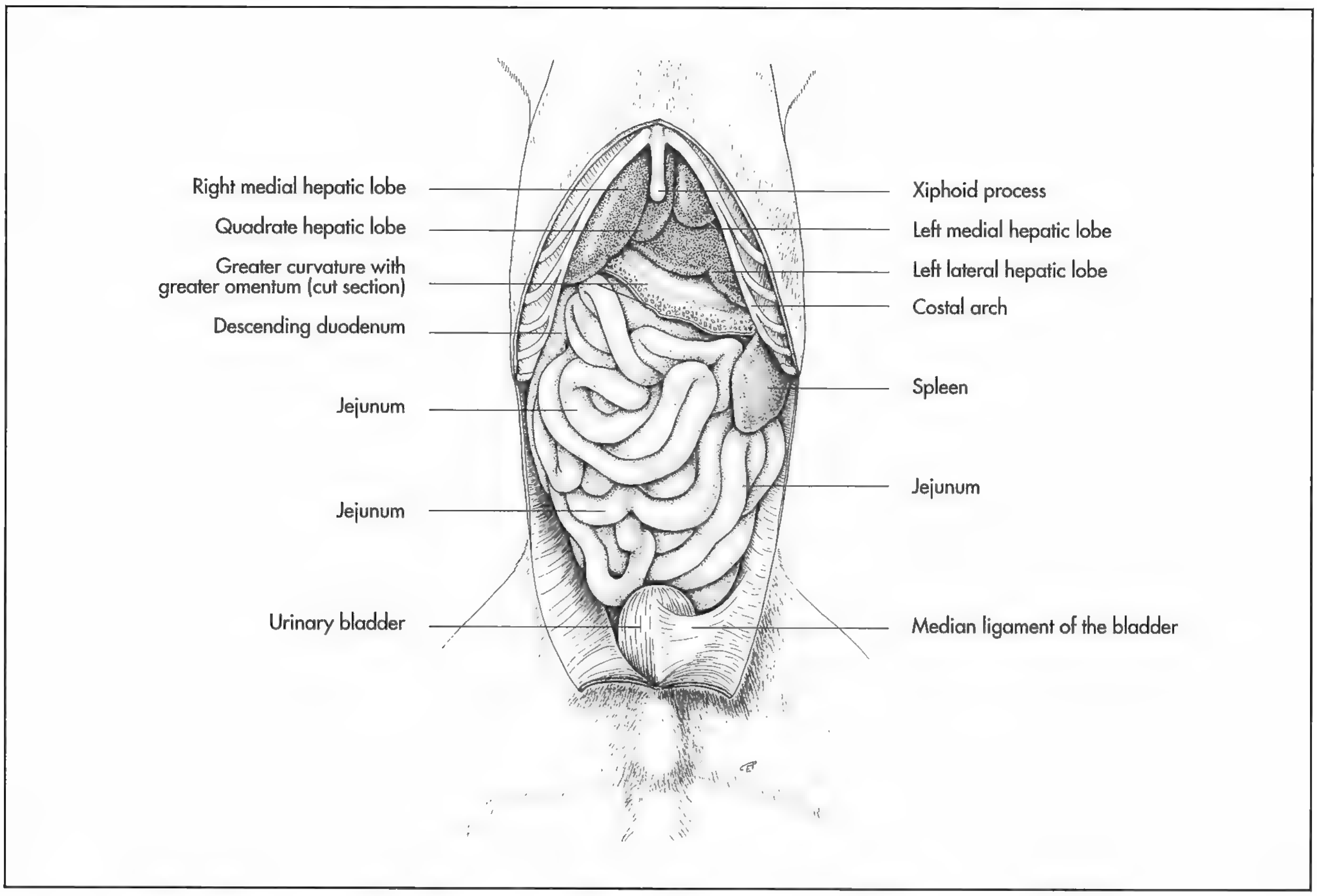

Fig 7-89. Abdominal organs of the dog in situ, ventral aspect, greater omentum removed, schematic.

er extensive lesser omentum allows a great range of movement to the stomach. This is held responsible for the high prevalence of gastric torsions (Torsio ventriculi) in the dog, a life-threatening condition occurring in middle-sized and large breeds.

The **cranial part of the duodenum** is connected with the liver by the hepatoduodenal ligament, a remnant of the ventral mesentery present in the embryo. Within the hepatoduodenal ligament passes the common bile duct (Ductus choledochus) from the liver to the duodenum. The mesentery of the descending duodenum includes the right lobe of the pancreas.

Both the pancreatic and the bile ducts open into the duodenum (Fig. 7-82). (A more detailed description is given within this chapter in the section about the accessory glands of the intestinal tract.)

Jejunum

The jejunum is the longest part of the small intestine between the duodenum and the ileum. It is also the **most mobile** and free part of the entire alimentary canal, due to the **long mesojejunum** which suspends the jejunum and ileum from the abdominal roof (Fig. 7-85 to 88).

The **mesojejunum** is continuous with the mesoileum and has the form of a large fan hanging from the abdominal roof with the convoluted jejunum and ileum located in its free distal border. The very short, bunched portion with which it attaches to the aorta is known as the **root of the mesentery** (radix mesenterii). It includes the **cranial mesenteric artery,** the **large mesenteric plexus of nerves** that surround the artery and **intestinal lymphatics.** The free border is much longer and folded or ruffled since it follows the turns of the intestine.

The distinction between the jejunum and ileum is rather arbitrarily chosen and the ileum is defined at the terminal part of the small intestine to which the **ileocecal fold** (plica ileocaecalis) attaches. In carnivores the jejunal coils occupy the ventral part of the abdomen between the stomach and the bladder, lying on the deep layer of the greater omentum. The long mesojejunum imposes little restraint, which allows the gut to move freely in response to respiratory and other movements.

In the pig the jejunum is also suspended by a long mesentery and its coils share the caudoventral part of the abdomen with the mass of the ascending colon. Since the latter lies largely in the left half of the abdominal cavity the jejunum lies more to the right (Fig. 7-87).

In ruminants the large rumen occupies the left half of the abdomen, thus pushing the intestines to the right (Fig. 7-76 and 77). The position of the jejunal coils depends on the fullness of

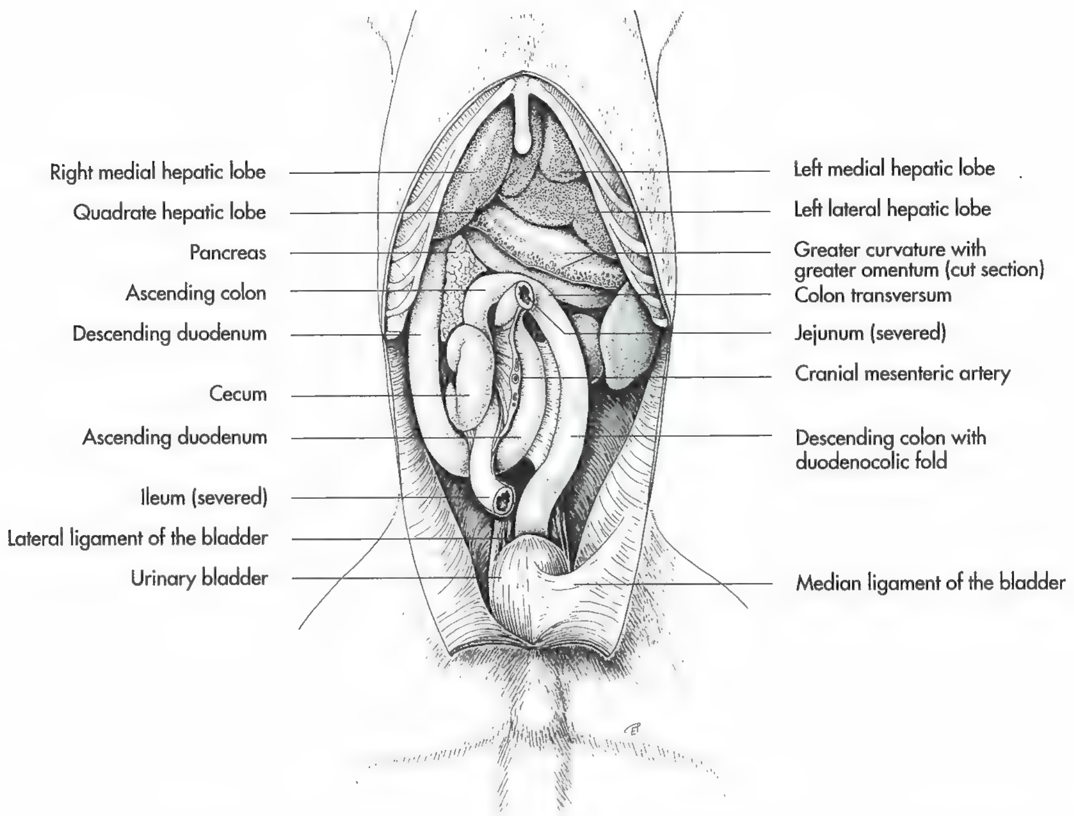

Fig 7-90. Abdominal organs of the dog in situ, ventral aspect, greater omentum and jejunal coils removed, schematic (Dyce, Sack and Wensing, 1991).

the rumen and the size of the uterus. Usually it lies, together with the ascending colon, within the supraomental recess, but some coils may also be found behind the rumen against the left flank. In ruminants and the pig the ascending colon is partly adherent to the right surface of the mesojejunum. Lymphoid tissue is generously spread throughout the mucosa and both solitary and aggregated nodules occur. Aggregated nodules form large (up to 25 cm long) Peyer-patches and can be distinguished by their irregular surface. Usually one of these patches extends through the ileum into the large intestine.

In the horse most of the jejunum is found within the left dorsal part of the abdomen. A considerable degree of mobility is provided to the jejunum by its long mesentery (Fig. 7-88). This is held responsible for the high prevalence of displacements of the gut, e.g. through the epiploic foramen into the omental bursa and for other conditions, such as invaginations and torsions, which can lead to colic.

Ileum

The ileum is the rather short terminal part of the small intestine. The distinction between the jejunum and the ileum is defined by the proximal extent of the **ileocecal fold** (plica ileocaecalis) (Fig. 7-85 to 88). It ends at the ileocecocolico junction with the ileal opening on the ileal papilla, the exact location varying between the different domestic mammals (Fig. 7-92)

It is more muscular and hence firmer than the jejunum and the mucosa is rich in lymphoid tissue, which aggregate to form Peyer-patches. The well-developed muscular layer is responsible for the uni-directional transportation of the ingesta into the cecum.

In the horse, dysfunction of the nervous supply to the ileum leads to a permanent contraction of the muscular coat of the ileum, which can result in impaction and thus colic. On rectal palpation a characteristic finding is the firm ileum passing from the left-ventral part of the abdomen right-dorsally.

Large intestine (intestinum crassum)

The large intestine can be divided into the following parts in all domestic mammals (Fig. 7-85 to 88):

- **Cecum,**
- **Colon,** which is further subdivided into:
  - Ascending colon (colon ascendens),
  - Transverse colon (colon transversum),
  - Descending colon (colon descendens) and
- **Rectum.**

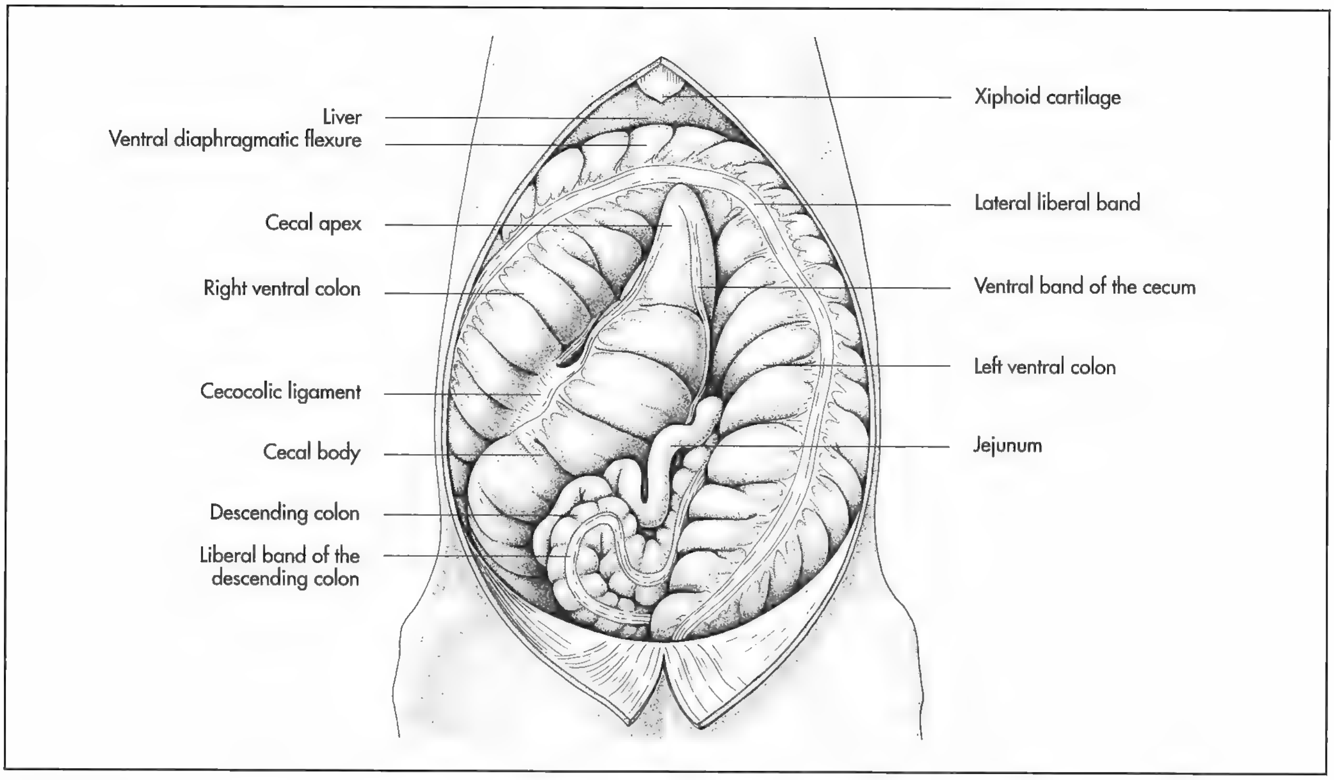

Fig 7-91 Cecum and colon of the horse in situ, ventral aspect, schematic (Ghetie, Pastea and Riga, 1955).

Cecum

The cecum is usually described as the first part of the large intestine. It is a blind-ending tube, which is demarcated from the colon by the entrance of the ileum (Fig. 7-85ff, 90 and 91). It communicates with the ileum through the **ileal orifice** (ostium ileale) and with the colon through the **cecocolic orifice** (ostium caecocolicum).

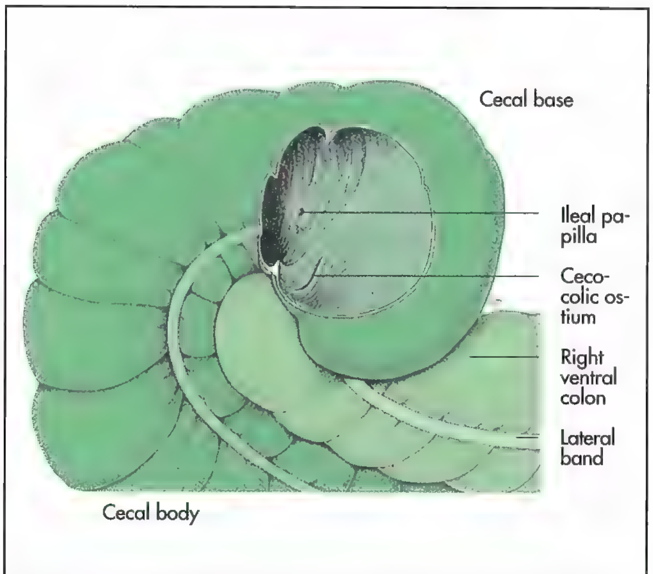

Fig. 7-92. Ileal papilla and cecocolic ostium in the horse, schematic.

The vermiform apex of man is **not present** in the domestic mammals.

In carnivores, ruminants and in the horse the cecum lies in the right half of the abdomen, in the pig it is on the left. It is attached to the ileum by the **ileocecal fold** (plica ileocaecalis), which defines the proximal extent of the ileum. In the dog the cecum is short and is drawn into a spiral. Unlike in the other domestic mammals, it does not have a direct communication with the ileum, but joins the colon, which forms a continuous tube with the ileum, to one side.

In the cat the cecum is even shorter and has the shape of a comma.

Cecum of the horse

The cecum of the horse has an enormous capacity of up to 30l and is on average about 1m long. It consists of a **base** (caput caeci) dorsally, a curved tapering **body** (corpus caeci) and a blind-ending **apex** (apex caeci) cranio-ventrally (Fig. 7-88 and 91).

The **base** lies in the right dorsal part of the abdomen in contact with the abdominal roof in the lumbar region where it forms a retroperitoneal attachment. The **cecocolic orifice** is a transverse slit, formed by a constriction of the ascending colon. In the dead specimen it admits only couple of fingers, while in the living animal it will generally allow the passage of a hand.

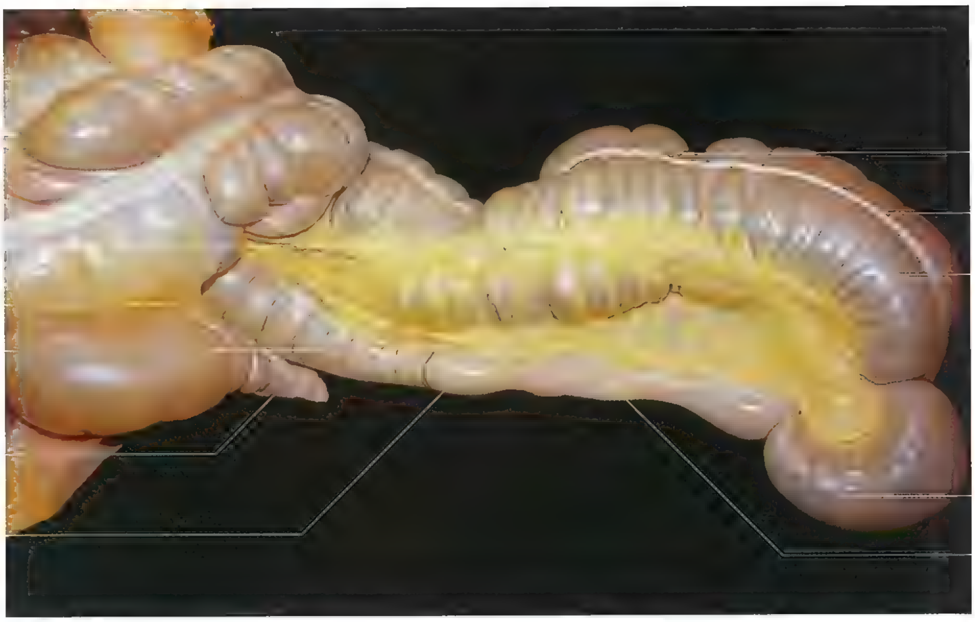

Fig 7-93. Large intestine of a horse.

The ileum opens on the **ileal papilla** (papilla ilealis) (Fig. 7-92), a conical projection including the **ileal spincter** (m. sphincter ilei) and a **venous plexus,** which control the ileal orifice. Based on its embryologic development the base of the cecum is actually the initial part of the ascending colon. Therefore the term **ileal orifice** (ostium ileale) is used in the horse, even though the ileum leads directly into the cecum and does not open on the the border to the ascending colon, as it does in the other domestic animals (except in the dog). The cecocolic junction is marked by the **cecocolic orifice** (ostium caecocolicum).

At first, the body of the cecum lies against the **right flank,** but as it runs cranioventrally it also passes more medially between the ventral parts of the ascending colon. It terminates with the apex close to the xiphoid cartilage on the ventral abdominal floor.

The **longitudinal layer** of the muscular layer is concentrated in **bands** visible on the external surface as **taenia,** between which the cecal wall is ruffled into four **rows of sacculations** (haustra) (Fig. 7-91 and 94). There are **four taenia** over most of the cecum, a medial, lateral, dorsal and ventral band, but the number diminishes towards the apex.

The **cecal vessels** and **lymph nodes are** located along the medial and lateral taenia. The dorsal band provides attachment to the **ileocecal fold** (plica ileocaecalis), which extends between the cecum and the ileum, the lateral band to the **cecocolic fold** (plica caecocolica) extending between the cecum and the ascending colon. The ventral band remains free. The different character of each taenia provides important anatomical landmarks, as do the varying numbers of taenia of the colon during surgery. The interior is marked by numerous folds, which correspond to the external divisions of the haustra.

In the horse the cecum is responsible for the digestion of complex carbohydrates such as cellulose. The ingesta are transported into the colon, while reflux into the ileum is prevented by the ileal papilla. The regular transportation of ingesta from the ileum into the cecum can be heard on auscultation of the right dorsal quadrant of the caudal abdomen, which is done in the assessment of colic. Disorders of cecal function may result in impaction or gas distension, which are a common cause of colic in the horse.

Cecum of the pig and ruminants

The cecum of the pig is a cylindrical blind-ending sac, which lies in the left half of the abdomen with its apex pointing caudoventrally. It has **three longitudinal muscle bands** (taeniae) with **three rows of sacculations** (haustra) between them. The ventral band provides attachment to the ileocecal fold, the lateral and medial bands remains free. The relatively small cecum of ruminants is rather featureless and has neither taenia nor haustra (Fig. 7-77 and 86). It is located in the right half of the abdomen within the supraomental recess with its blind-ending apex pointing caudally.

Colon

Following human anatomic nomenclature the colon (Fig. 7-85 to 88) is divided into three parts:

- Ascending colon (colon ascendens),
- Transverse colon (colon transversum),
- Descending colon (colon descendens).

The anatomical arrangement which forms the base of this division is only found in dogs and cats. In these species the short ascending colon passes cranially on the right, the transverse colon runs from right to left, cranial to the root of the

mesentery. The long descending colon passes left of the mesenteric root caudally, where it on reaching the pelvic cavity continues as the rectum. In the other domestic mammals the form and topography of the colon is more complex with the ascending colon showing the greatest modifications.

Colon of the horse

The colon of the horse consists of a large ascending colon, which is arranged in two U-shaped loops laying on top of each other, a short transverse colon and a long descending colon. Due to the considerable difference in diameter the first two portions are also referred to as the "large colon", the third as the "small colon" (Fig. 7-88, 91, 93 and 90).

Ascending colon (colon ascendens)

The ascending colon can be subdivided into four parallel limbs connected by three flexures with the following proximo-distal sequence:

- Right ventral colon (colon ventrale dextrum),
- Sternal flexure (flexura diaphragmatica ventralis),
- Left ventral colon (colon ventrale sinistrum),
- Pelvic flexure (flexura pelvina),
- Left dorsal colon (colon dorsale sinistrum),
- Diaphragmatic flexure (flexura diaphragmatica dorsalis),
- Right dorsal colon (colon dorsale dextrum).

The ascending colon begins with the right ventral colon at the cecocolic orifice. The right ventral colon continues cranioventrally almost parallel to the right costal angle. On reaching the xiphoid region it is deflected across the midline as the sternal flexure and passes caudally as the left ventral colon on the abdominal floor towards the pelvis. Just cranial to the pelvic inlet it forms the pelvic flexure by turning about 360 degree dorsally, after which it continues as the left dorsal colon. The left dorsal colon runs cranially again on top of the left dorsal colon towards the diaphragm where it joins the right dorsal colon at the diaphragmatic flexure. The right dorsal colon is the shortest, but widest part of the ascending colon and runs first caudally until it is deflected medially to become the transverse colon.

The different portions of the ascending colon can not only be distinguished by their topography, but have other characteristic features, which are important for the identification of the different parts during laparotomy. The right and the left ventral colon are characterised by **four bands** (taeniae) with **four rows of sacculations** (haustra) between them (Fig. 7-94). The lateral and medial mesocolic bands (taenia mesocolica lateralis et medialis) run on the dorsal surface and provide attachment to the mesocolon. The medial band also conveys blood vessels, nerves and lymphatics. Numerous lymph nodes are located along this band and at the caudal part of the right ventral colon the cecocolic fold attaches to it. The other two bands are found on the ventral surface and are mainly composed of soft tissue rich in elastic fibres. It is hypothesised that the ventral bands have mainly a supporting function, while the dorsal ones, being rich in muscle fibres and nervous tissue, are responsible for contraction.

At the junction to the pelvic flexure three of the four bands disappear and the **pelvic flexure** and the following **left dorsal colon** have only **one mesocolic longitudinal band.** The pelvic flexure is also distinguished by a marked reduction in diameter and it marks the boundary between two functional units of the colon (Fig. 7-88).

In the **ventral parts of the colon** many important digestion and absorption mechanisms take place, while the dorsal parts of the colon play only a minor role in digestion, but are mainly responsible for transportation of the ingesta. The reduction in diameter together with the sudden change in direction and the decrease in the fluidity of the ingesta render this location predisposed for impaction. The left dorsal colon is narrow, but widens gradually. Close to the diaphragmatic flexure two additional bands appear on the dorsal surface. Thus the **diaphragmatic flexure** and the right dorsal colon are marked by **three bands,** two on the dorsal and one on the ventral surface with relatively indistinct rows of sacculation between them (Fig. 7-91). These taeniae are responsible for the transportation of the ingesta into the transverse colon.

The **right dorsal colon** is by far the widest part of the colon and is therefore also referred to as the ampulla coli. It is a common site for enteroliths, which can reach football size and may lead to obstruction of the transverse colon, causing colic.

The **dorsal attachment** of the ascending colon is limited to the right dorsal colon, which is adherent to the abdominal roof, the base of the cecum, the root of the mesentery and the pancreas. This anatomical arrangement allows the left ascending colon to twist around its common axis **(colon torsion),** which causes severe colic symptoms and requires immediate surgical correction.

The **ventral parts of the colon** are connected to the dorsal parts by the mesocolon which includes blood vessels, nerves and lymph nodes (lnn. colici).

Transverse colon (colon transversum)

The short transverse colon passes from the right to the left cranial to the root of the mesentery. It is marked by two bands and rapidly funnels to the diameter of the descending colon (Fig. 7-88), which succeeds the transverse colon at the level of the left kidney. The transverse colon is involved in the dorsal attachment of the right dorsal colon.

Descending colon (colon descendens)

The descending colon is similar to the jejunum in diameter and between 2–4 m long. It is also suspended by a long mesentery (mesocolon descendens), but can be distinguished from the mesojejunum by its higher content of fat. The descending colon carries two bands, the antimesenterial taenia and the mesenterial taenia to which the mesocolon attaches. The two prominent bands draw the descending colon into two rows of distinct sacculations, which are occupied by the characteristic faecal balls of this species (Fig. 7-88).

Colon of the pig

The colon of the pig is divided into the usual three parts with the transverse and descending colon being similar to the

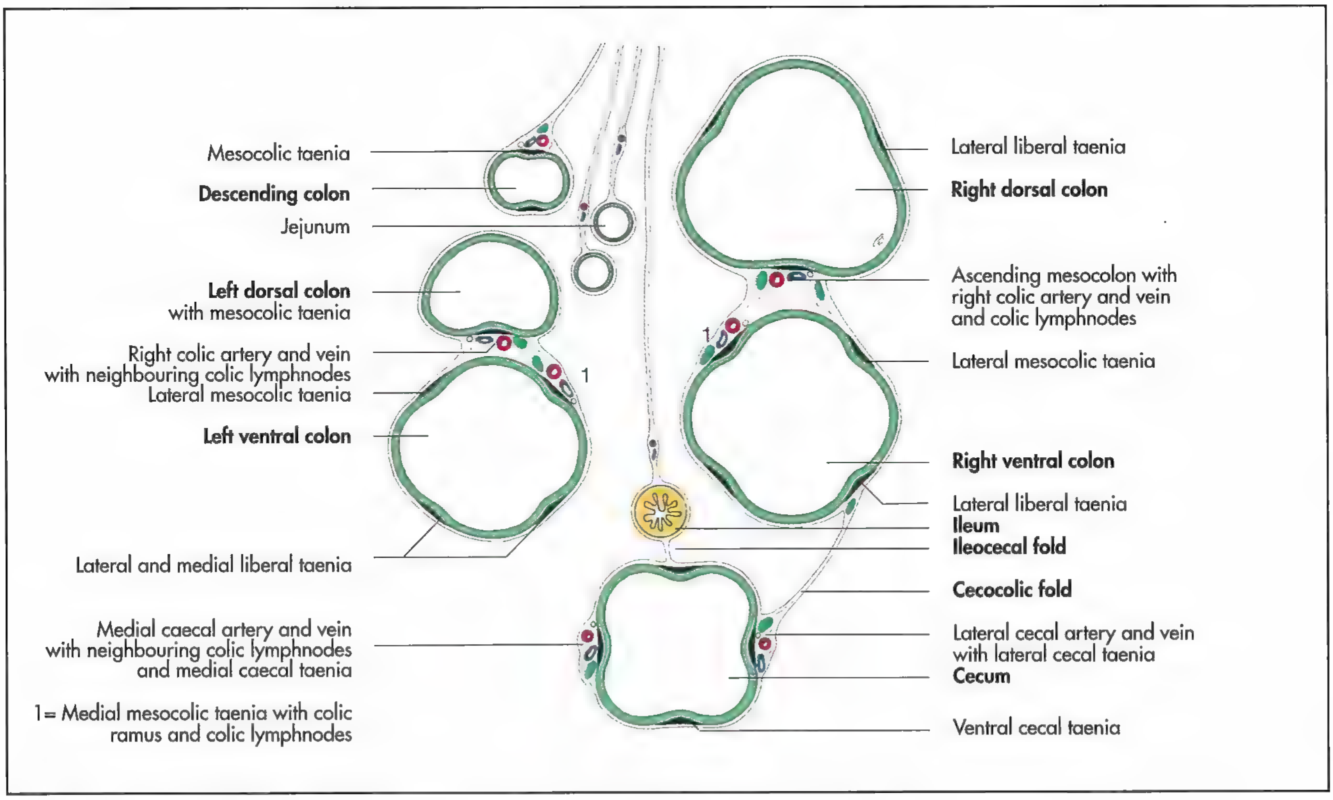

Fig. 7-94. Transverse sections of the colon in the horse, schematic (caudal aspect) (Habel, 1978).

simple arrangement found in dogs (Fig. 7-87). The ascending colon however is greatly elongated and coiled to form a cone-shaped organ. The base of this cone is attached to the abdominal roof in the left half of the abdomen and the apex points ventrally, its exact position is dependant on the degree of filling of the stomach.

After originating from the cecum ventral to the left kidney, the ascending colon forms **centripetal turns** passing clockwise (viewed from above) to the apex of the cone. It then reverses forming the **central flexure** (flexura centralis) and returns to the base in tight counterclockwise turns. The centripetal turns are located on the outside of the cone, the **centrifugal turns** are located inside the cone covered by centripetal ones. The centripetal ones are marked by two bands with two rows of sacculations between them, which are not present in the centrifugal turns.

Colon of the ruminants

The colon is divided into the usual ascending, transverse and descending parts (Fig. 7-86). The ascending colon is by far the longest part and has a characteristic spiral arrangement.

After leaving the cecum the ascending colon forms a **sigmoid flexure** (ansa proximalis coli), the first part being cranially convex, the second caudally convex. It then narrows and turns ventrally to form a double **spiral** (ansa spiralis), which is in contact with the left side of the mesentery (Fig. 7-85). **Two centripetal turns** (gyri) are reversed in the **central flexure** of the spiral and succeeded by **two centrifugal turns** in the ox. There are three centripetal turns in the sheep and four in the goat, followed by the same number of centrifugal turns. The centrifugal turns of small ruminants have a pearl-string appearance due to the segmented contents characteristic of the faeces of these species. In small ruminants the last centrifugal turn spirals away from the coil to come close to the jejunum, surrounding the jejunal lymph nodes. While the whole spiral has the form of a flat disk in the ox, it is arranged to form a low cone in the small ruminants.

After the last centrifugal loop of the spiral the ascending colon continues into a **distal loop** (ansa distalis coli) which carries it first towards and then away from the pelvis to join the transverse colon. The **short transverse colon** crosses the midline cranial to the mesenteric root and continues caudally as the descending colon. This part of the colon is usually embedded in fat and fused to adjacent parts of the intestine. Before joining the rectum at the pelvic inlet it forms a sigmoid flexure, the looseness of which allows a considerable range of movement to the hand of the examiner during rectal palpation.

Intestinal landmarks

- The mesentery of the descending duodenum always includes the right part of the pancreas,
- the caudal flexure of the duodenum surrounds the cranial mesenteric root caudally,
- the duodenocolic fold (plica duodenocolica) marks the distal end of the duodenum and extends to the descending colon,

- the ileocecal fold marks the length of the ileum and extends to the cecum (in the horse it attaches to the dorsal band),
- the transverse colon passes cranial to the cranial mesenteric root,
- in the horse the cecocolic fold extends between the cecum and the caudal part of the medial mesocolic band of the left ventral colon,
- in the horse the different parts of the colon can be identified by the numbers of taenia:
  - four bands: left and right ventral colon, sternal flexure,
  - three bands: diaphragmatic flexure, right dorsal colon,
  - two bands: descending colon and
  - one band: pelvic flexure, left dorsal colon.

Rectum

By entering the pelvis the descending colon becomes the rectum, which passes caudally as the most dorsal of the pelvic viscera. Most of the rectum is suspended by the mesorectum, but the terminal part is wholly retroperitoneal. The retroperitoneal space is filled with soft tissue rich in fat. Before joining the short anal canal, which opens to the outside with the anus, it becomes dilated to form the rectal ampulla (Fig. 7-85 to 88).

Anal canal and adjacent structures

The short anal canal is the terminal part of the alimentary canal, which opens to the outside with the anus. The anus is controlled by the internal and external anal sphincters. The internal sphincter consists of smooth muscle and is a modification of the circular layer of the muscle coat of the rectum, the external sphincter is striated muscle arising from the caudal vertebrae. At the anus the columnar intestinal epithelium is replaced by the stratified cutaneous epithelium of the skin.

In **carnivores** the mucosa of the anal canal is divided into three consecutive annular zones (Fig. 7-95). These are from cranial to caudal:

- Columnar zone (zona columnaris),
- Intermediate zone (zona intermedia),
- Cutaneous zone (zona cutanea).

The **columnar zone** is the first zone following the rectum, the division of the two marked by the indistinct anorectal line. Its mucosa has a stratified squamous epithelium and is rich in lymphoid tissue. It is arranged in **longitudinal folds** (columnae anales) with grooves (sinus anales) between them.

The **intermediate zone** has the form of a sharp-edged scalloped fold, which is divided into four arcs. It ends at the anocutaneous line. The anal glands are tubuloalveolar glands, which produce a fatty secretion and open to the outside in the columnar and intermediate zone.

The **cutaneous zone** surrounds the anus and its extent varies with the size of the underlying circumanal glands, which

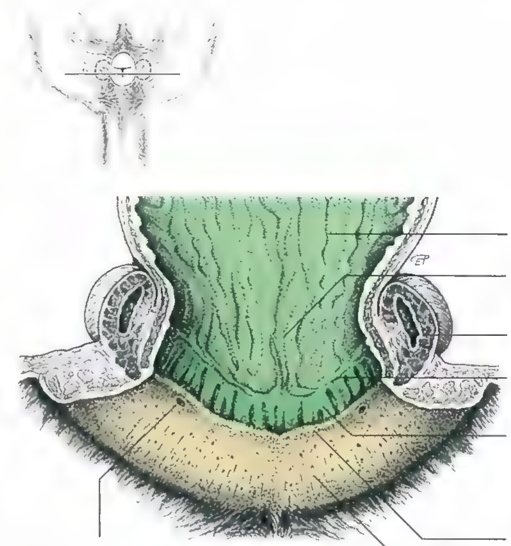

Fig. 7-95. Anal canal in a dog, schematic.

grow throughout life. The excretory ducts of anal sacs open on the surface of the cutaneous zone.

The **anal sacs** (sinus paranalis) are pea to marble sized sacs, located between the inner smooth and the outer striated sphincter muscle of the anus. Their walls contain the glands of the **anal sac** (glandulae sacci paranales), which are composed of large, coiled apocrine tubules. These glands discharge their foul-smelling, serous to pasty secretion into the anal sacs, which functions for territorial scent marking.

The anal sacs are of considerable clinical importance, since they are commonly diseased in the dog. They become frequently enlarged, due to accumulated secretion or may become abscessed and painful, causing constipation.

Glands associated with the alimentary canal

The **liver** and **pancreas** are the two glands closely associated with the alimentary canal. Among many other important function both organs produce substances which play a central role in gastrointestinal digestion.

Liver (hepar)

The liver is the largest gland in the body and is both **exocrine** and **endocrine** in function. Its exocrine product, bile, is stored and concentrated in the gallbladder before being drained into the duodenum. However, a gall bladder is not essential, and is lacking in several species, including the horse. The bile is responsible for emulsifying the fatty compounds prior to absorption. It also contains the end-products of the

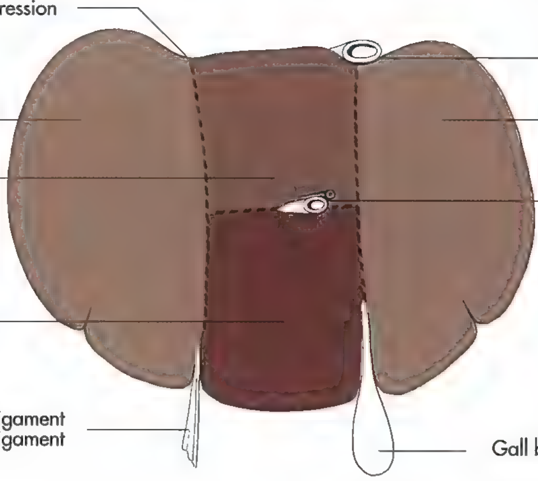

Fig 7-96. Lobation pattern of the liver, schematic.

haemoglobin metabolism and by-products of certain metabolized drugs.

Its endocrine substances are released into the blood stream and play an important role in the fat, carbohydrate and protein metabolism. The anatomical arrangement of the venous system of the gastrointestinal tract ensures that all products of digestion, which are conveyed in the blood stream after absorption, pass the liver before entering the general circulation. It serves as a storage of glycogen and in juvenile animals it functions as an haematopoetic organ. (A more detailed description of the function of the liver can be found in physiology textbooks.)

Weight

There is a great variation in size between the different species and even between individuals of the same species, largely depending on body weight and age. Average values are: 2% of body weight in the cat, 3–4% in the dog, 2–3% in the pig and 1–1.5% in herbivores. In the embryo it is substantially heavier and fills most of the abdominal cavity. In the juvenile animal is still relatively larger than in adults due to its function in haematopoesis. It often shows considerable atrophy in old age.

Form, position and species specific variations

The liver is located in the thoracic part of the abdomen, immediately behind the diaphragm. The bulk of the liver lies to the right of the median plane, in ruminants the development of the rumen pushes the liver entirely into the right half of the abdomen. In the live animal the liver adapts to the form of adjacent organs, when fixed in situ it retains the conformation and impressions these impose.

It has a strongly convex surface towards the diaphragm (facies diaphragmatica) and a concave surface facing towards the other abdominal organs (facies visceralis). These two surfaces meet ventrolaterally in a **sharp-edged border** (margo acutus) and dorsally in a **blunt border** (margo obtusus). The visceral surface is marked by the **hepatic porta** (porta hepatis) through which the portal vein, the bile duct and the hepatic vessels enter or leave the organ and is closely related to the gallbladder.

In most species the liver is grossly divided into four main lobes by fissures that extend into the organ from the ventral border (Fig. 7-97 to 104):

- Left hepatic lobe (lobus hepatis sinister),
- Right hepatic lobe (lobus hepatis dexter),
- Caudate lobe (lobus hepatis caudatus) and
- Quadrate lobe (lobus hepatis quadratus).

The **lobation patterns** differ greatly among species. Species, in which the spine is very mobile, such as the dog and the cat, have more subdivisions than species with a more rigid spine (herbivores). It is hypothesised that the hepatic lobes easily glide over each other, when the spine is maximally flexed or extended. In those species where no fissures indicate lobation, a theoretical pattern is still applied by virtual lines extending from certain landmarks, which divides the liver into the four main lobes listed above (Fig. 7-96).

In carnivores the liver has **four lobes** and **four sublobes** as well as **two processes:** both, the left and right hepatic lobe are subdivided into medial and lateral lobes (lobus hepatis sinister (dexter) lateralis et medialis), and the caudate lobe is subdivided into the caudate (processus caudatus) and the papillar process (processus papillaris) (Fig. 7-97, 101 and 102). The liver of

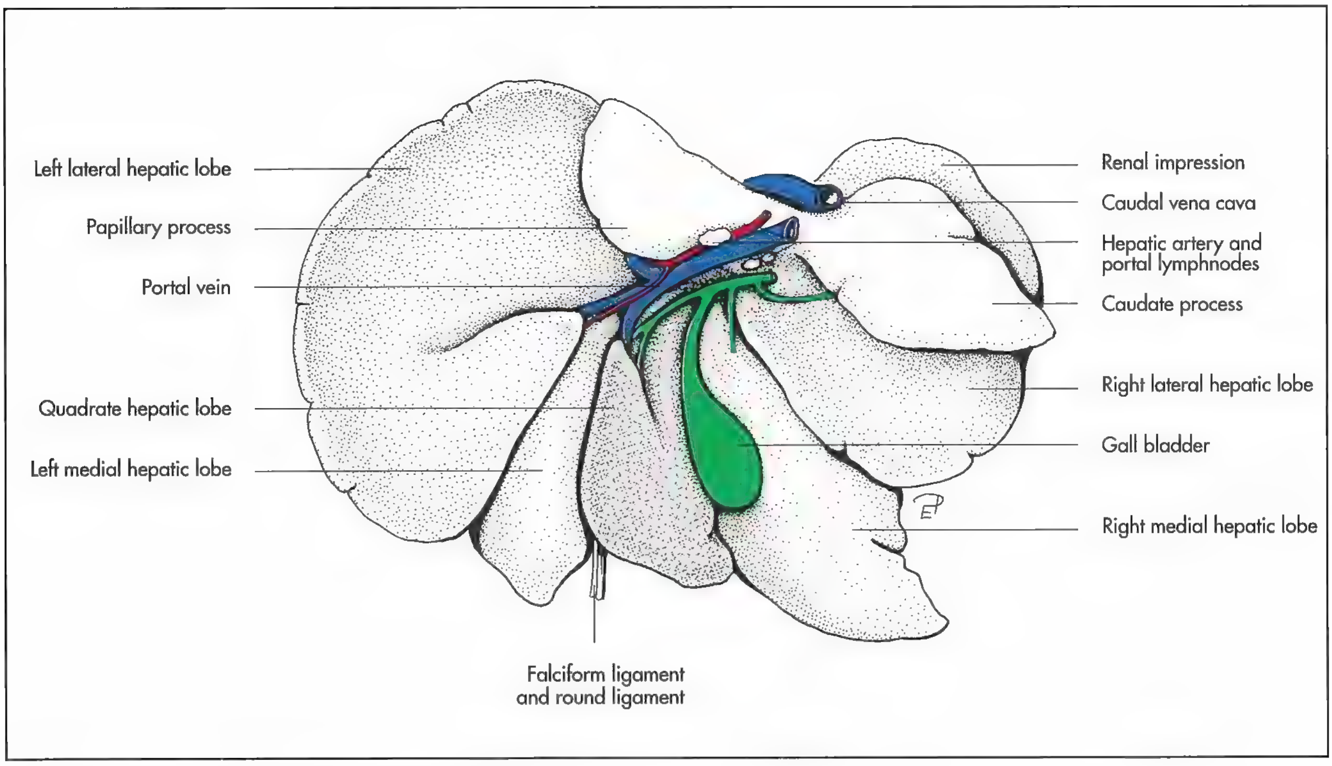

Fig 7-97. Liver of the dog, schematic, visceral surface.

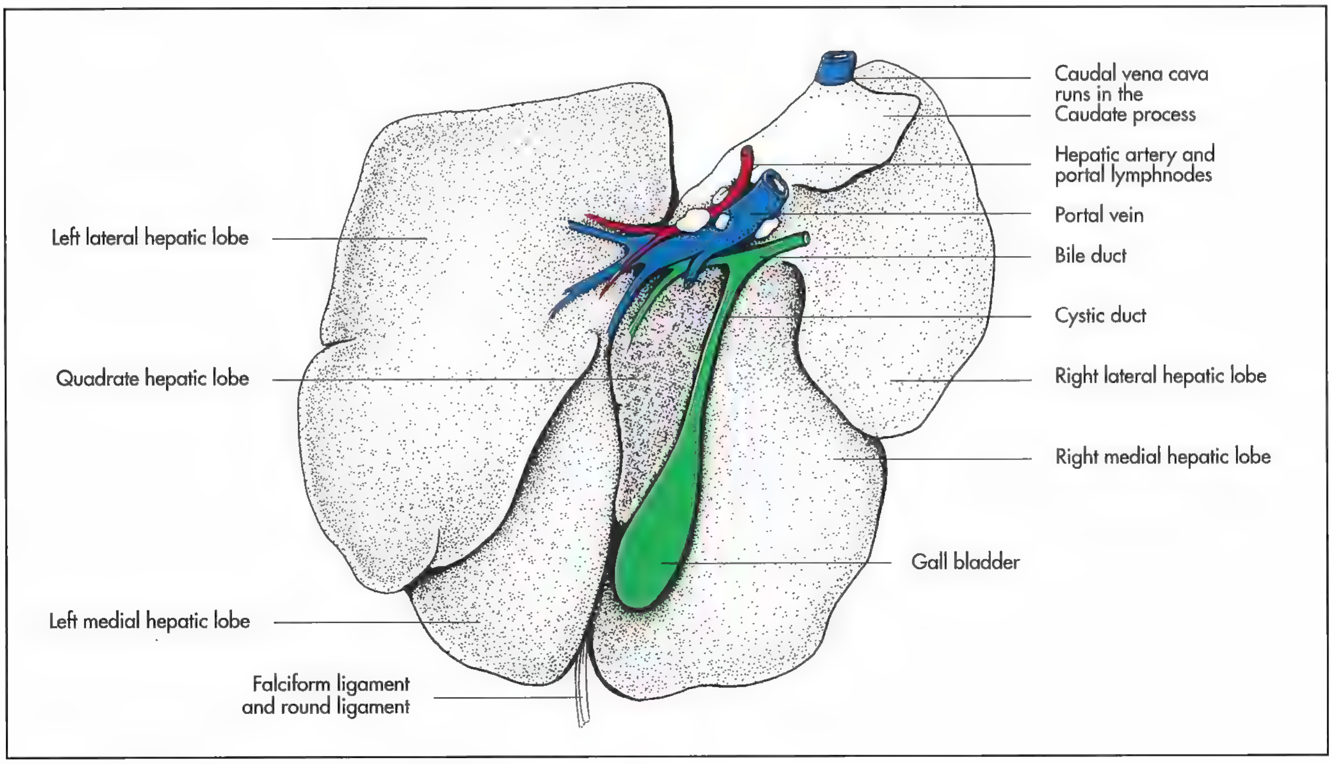

Fig 7-98. Liver of the pig, schematic, visceral surface.

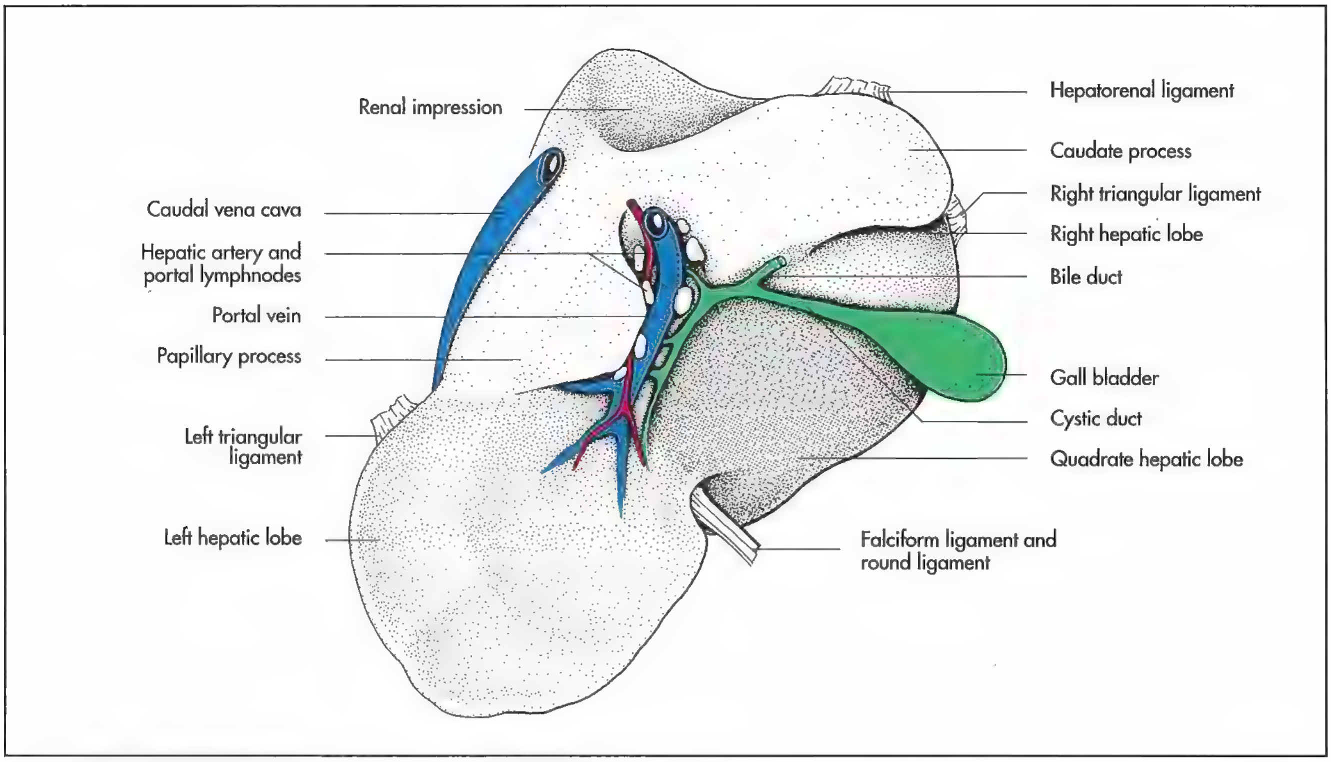

Fig 7-99. Liver of the ox, schematic, visceral surface.

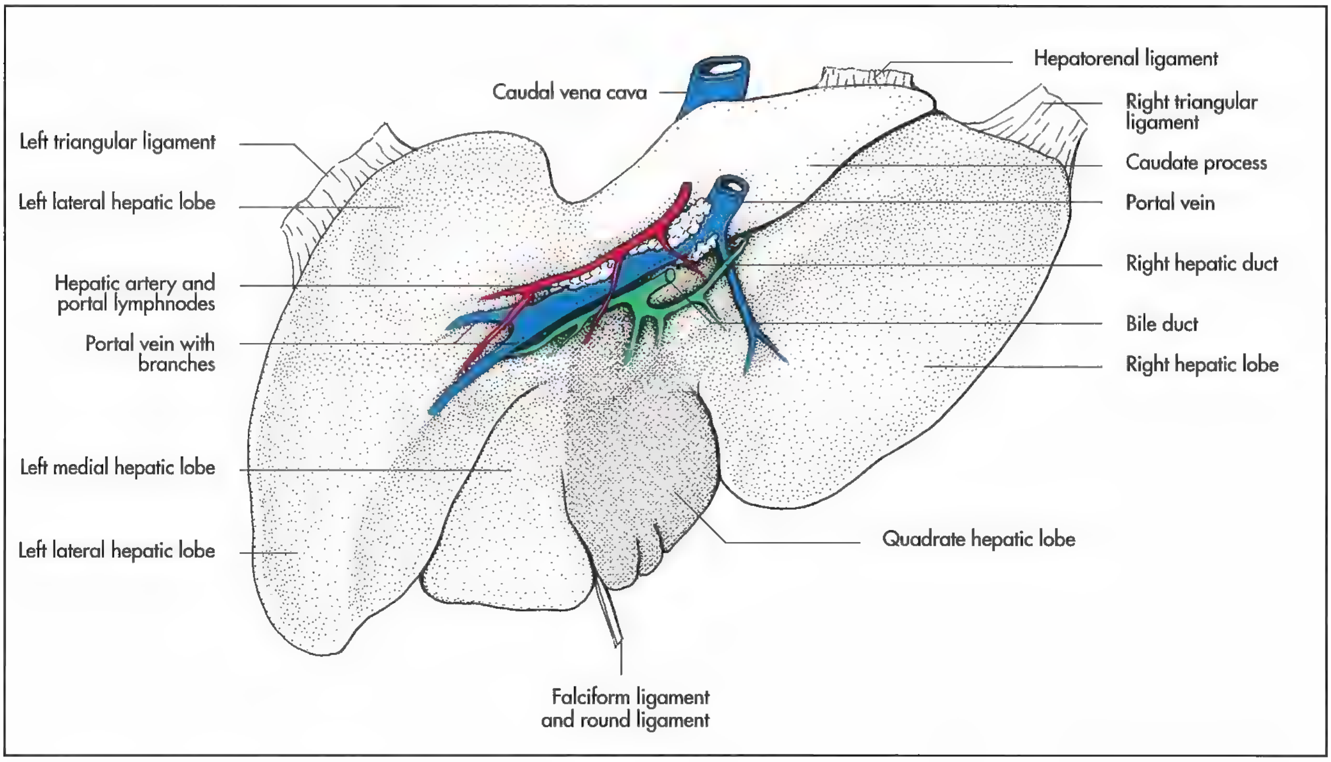

Fig 7-100. Liver of the horse, schematic, visceral surface.

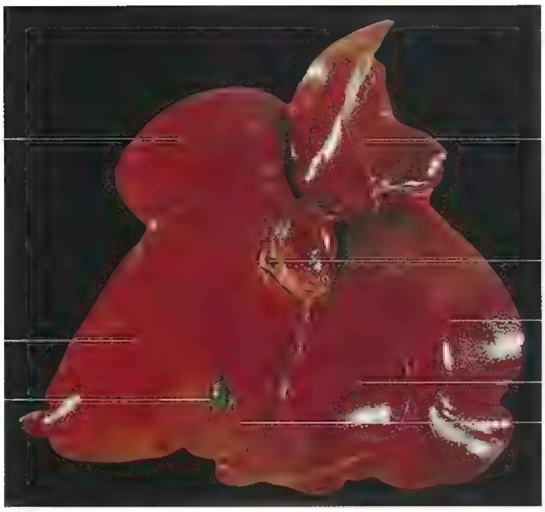

Fig 7-101. Liver of a cat, diaphragmatic surface (König, 1992).

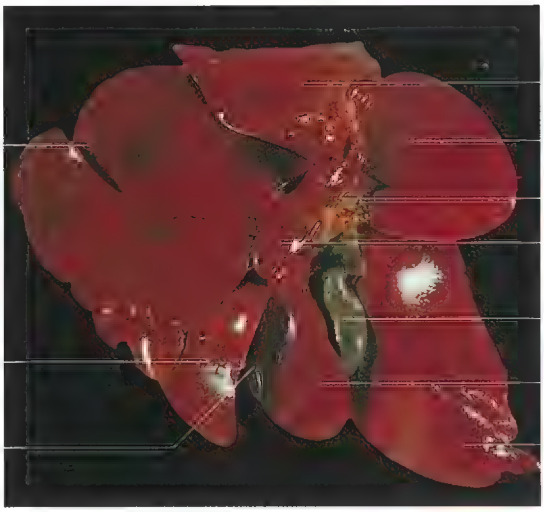

Fig 7-102. Liver of a cat, visceral surface (König, 1992).

the pig resembles that of the dog, but does not have a papillar process (Fig. 7-98, 103 and 104). In the horse the **left lobe** only is subdivided into **medial** and **lateral lobes,** while the right lobe remains undivided. The **caudate lobe** has a **caudate process,** but no papillary process (Fig. 7-100). The liver of ruminants has **no fissures** (Fig. 7-99). It consists of a **left** and **right hepatic lobe,** a **quadrate lobe** and a **caudate lobe,** the borders of which are defined by virtual lines drawn from anatomical landmarks illustrated in Fig. 7-96.

Several impressions and **indentations** can be identified on the specimen hardened in situ: the visceral surface is marked by the impressions caused by the stomach, the duodenum, the pancreas, the right kidney (except in the pig, where the kidney is located too far caudally) and various parts of the intestine, depending on the species. The left part of the dorsal margin carries the impression of the esophagus, the right part is excavated to receive the cranial pole of the right kidney. A sulcus medial to it transmits the caudal vena cava.

Structure

The free surface of the liver is almost completely covered by peritoneum, which forms its serous coat. It is fused to the underlying fibrous capsule, that encloses the whole organ. This interlobular connective tissue conveys blood vessels into the organ. The finer trabeculae divide the liver parenchyma into innumerable small units, the **hepatic lobules** (lobuli hepatis) (Fig. 7-105).

These lobules are particularly marked in the porcine liver, but are also grossly visible in carnivores, in which they appear as hexagonal areas of about 1mm in diameter. The hepatic lobules are the smallest grossly visible functional units of

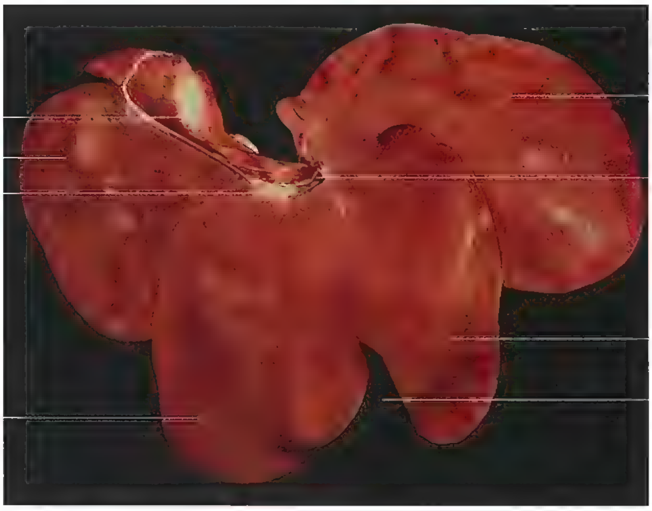

Fig 7-103. Liver of a pig, diaphragmatic surface.

Fig 7-104. Liver of a pig, visceral surface.

the liver and are composed of curved **sheets of hepatocytes** (laminae hepaticae), that surround blood filled cavities, known as the **liver sinusoids** (Fig. 7-106 and 107). Based on their vascular architecture the hepatic lobules can be grouped following different systems:

- Polygonal hepatic lobule with the single central vein in the centre,
- Periportal hepatic lobules with hepatic artery, vein and canaliculus in the centre.

Blood supply

The liver receives a generous blood supply through the **hepatic artery** (a. hepatica) and the **portal vein** (v. porta) (Fig. 7-108). The **hepatic artery,** a branch of the **celiac artery** (a. coeliaca), furnishes the nutritional supply of the liver. The hepatic artery enters the liver together with the portal vein at the hepatic porta on the visceral surface of the organ. Both vessels branch out along the fibrous septa together with the tributaries of the hepatic duct. The hepatic arteries supply the liver framework, the capsule, the intrahepatic biliary duct system, the walls of the blood vessels and the nerves before they finally drain-together with the branches of the portal vein into the liver sinusoids. Thus the parenchymal cells are bathed by mixed blood from the hepatic artery and the portal vein, so that they actually receive nutrition from both.

The **portal vein** has three branches which drain into it, the splenic vein, the cranial and the caudal mesenteric veins, which collect the blood from **all unpaired organs of the abdomen** (stomach, pancreas, intestines, spleen). It thus transports the functional blood to the liver. The contributing

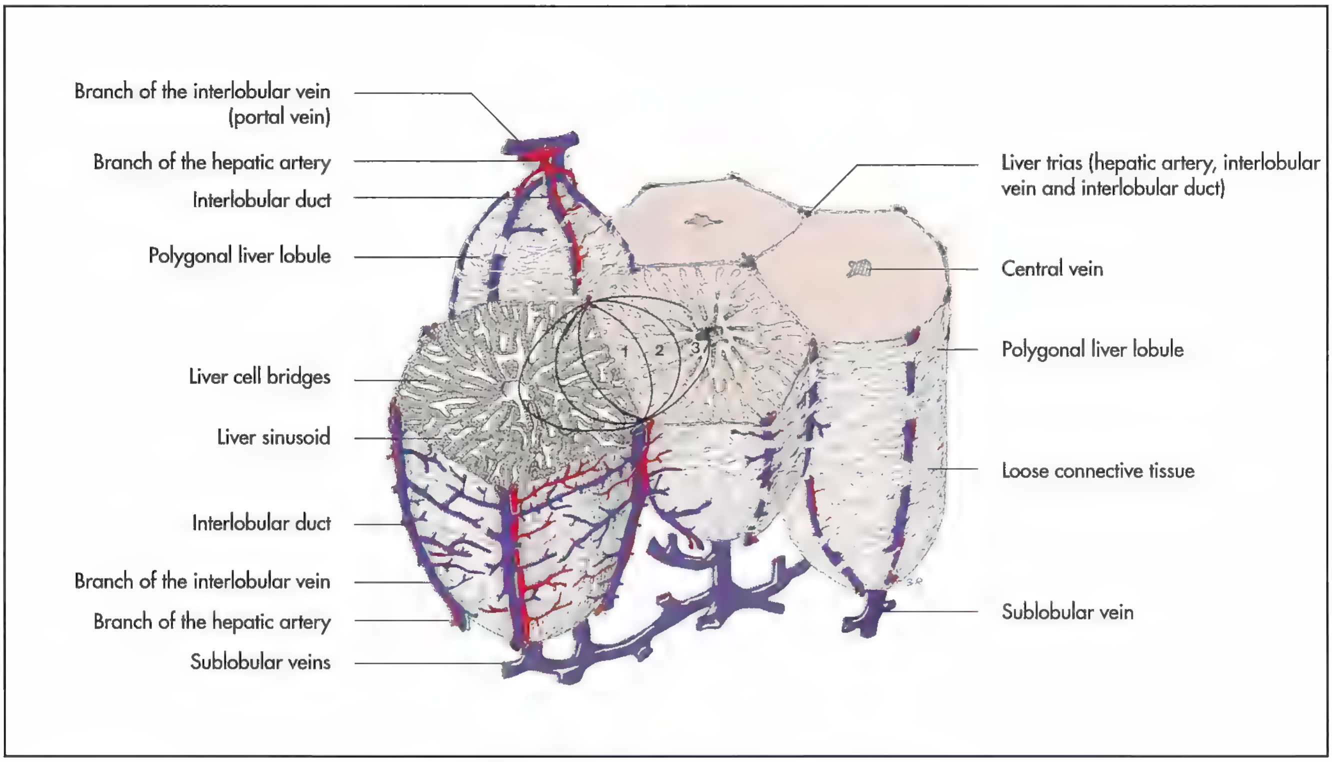

Fig 7-105. Hepatic lobules in relation to afferent and efferent vessels, three-dimensional, schematic (Liebich, 2004).

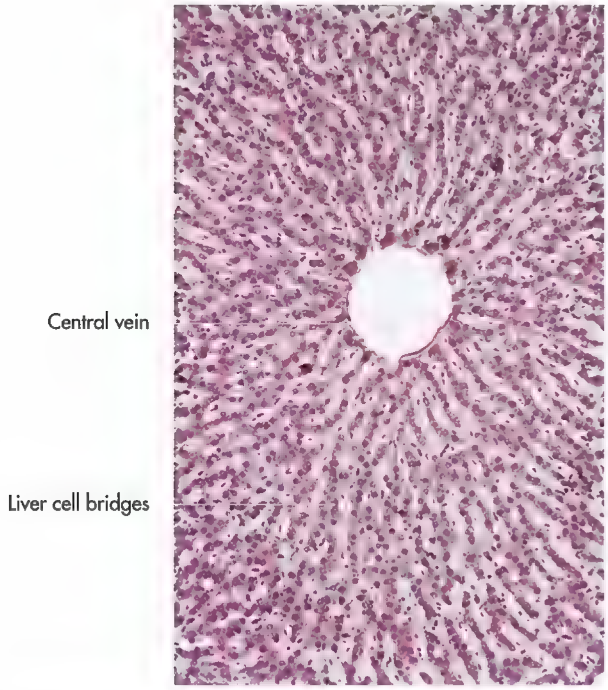

Fig 7-106. Histological section of a hepatic lobule of a pig showing a central vein and sheets of hepatocytes.

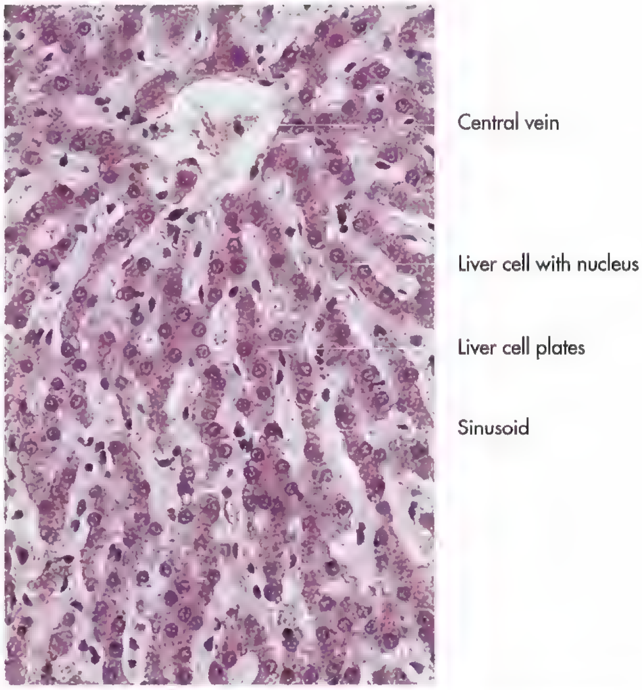

Fig 7-107. Histological section of a hepatic lobule showing a central vein, heaptocytes and liver sinusoids.

Fig 7-108. Corrosion cast of the liver of a dog after injection of the hepatic artery and the portal vein.

veins of the portal vein are connected with veins of the cardi-oesophageal region and of the rectoanal region. These constitute alternative routes, the blood can take when intrahepatic circulation is impaired, e.g. in the case of liver cirrhosis.

In the fetus the **ductus venosus,** a direct continuation of the umbilical trunk tunnels through the liver, is bypassing the hepatic circulation to join the caudal vena cava. This porto-caval shunt persists in some individuals (especially in the dog and cat) after birth and requires surgical intervention.

Venous drainage of the liver starts with the single central vein in the **middle of each hepatic lobule.** These veins collect the mixed blood of the hepatic artery and the portal vein after it had been mixed in the liver sinusoids and had been into contact with the hepatocytes. Adjacent **central veins** fuse to form the **sublobular veins,** which unite with each other to form the **hepatic veins.** These leave the organ on its diaphragmatic surface to finally empty into the **caudal vena cava.** A detailed knowledge of the internal ramification of the hepatic vessels is essential for hepatic surgery in man, but is not as important in veterinary medicine.

Innervation

The liver is innervated by both **sympathetic** and **parasympathetic nerves.** It receives afferent and efferent fibres from the ventral **vagal trunk** and sympathetic fibres from the **celiac ganglion.**

Lymphatics

The lymphatics of the liver drain into the **portal lymph nodes,** which are located within the lesser omentum close to the **hepatic porta.**

Ligaments

The liver is closely related to the ventral mesentery present during embryonic development. It has no supportive functions, but conveys blood vessels, nerves and lymphatics.

There are three distinct parts:

- Falciform ligament (lig. falciforme hepatis),
- Hepatoduodenal ligament (lig. hepatoduodenale),
- Hepatogastric ligament (lig. hepatogastricum).

The **falciform ligament** of the liver is a remnant of the ventral mesentery, that extends between the liver and the diaphragm and the ventral body wall. It includes the **umbilical vein** (v. umbilicalis) in its free borders during foetal life, which obliterates after birth to form the **round ligament** (ligamentum teres hepatis) (Fig. 7-97 to 100).

The **hepatoduodenal** and the **hepatogastric ligament** extend from the hepatic porta to the duodenum and stomach, respectively. They constitute the lesser omentum and convey the bile duct to the duodenum and the portal vein and the hepatic artery to the liver. It also contains the left and right gastric artery, where it attaches to the lesser curvature of the stomach. Fixation of the liver is achieved by the blood vessels entering the organ and by continuations of its serous and fibrous coats onto the diaphragm.There are three ligaments, which provide mechanical support to the liver:

- Left triangular ligament (lig. triangulare sinistrum),
- Right triangular ligament (lig. triangulare dextrum),
- Coronary ligament (lig. coronarium hepatis).

The **coronary ligament** surrounds the caudal vena cava during its short passage from the liver to the diaphragm. It is irregular

Fig 7-109. Bile drainage system of a sheep, corrosion cast (courtesy of Prof. Dr. Ana Carretero, Barcelona).

in outline and its border gives rise to the triangular ligaments. The **triangular ligaments** extend between dorsal part of the liver on each side and the diaphragm (Fig. 7-97 and 98).

Bile ducts

The bile is produced by the sheets of hepatocytes and discharged into the **bile canaliculi,** also termed **bile capillaries,** that lie between these cells without having a wall of their own. These capillaries unite to form the **interlobular ducts** (ductuli interlobulares), which lie in the interstitial tissue between the lobules together with the branches of the hepatic artery and the portal vein. The interlobular ducts unite to form the **lobar ducts** (ductus biliferi). (A more detailed descripton can be found in histology textbooks.)

The **extrahepatic bile ducts** consist of the **hepatic ducts** from the liver (ductus hepatici), the **cystic duct** (ductus cysticus) to the gallbladder and the **bile duct** (ductus choledochus) to the duodenum (Fig. 7-109).

In the horse and in ruminants the lobar ducts unite to form a **left** and a **right hepatic duct** (ductus hepaticus sinister et dexter), which again unite to form the **common hepatic duct** (ductus hepaticus communis). In the pig the lobar ducts of the left hepatic lobes unite to form the left hepatic duct, while the ducts of the right lobes drain separately into the common hepatic duct.

In carnivores each hepatic sublobe has its own lobar duct which drains into the cystic duct. These species do not have left, right or common hepatic ducts. The beginning of the bile duct is marked by the junction of the common hepatic duct or the last lobar duct with the cystic duct. The bile duct opens into the proximal part of the duodenum on the **major duodenal papilla.**

Gall bladder (vesica fellea)

The sac-like gall bladder lies in a fossa on the visceral surface of the liver close to the hepatic porta. In the cat it is also visible on the diaphragmatic surface (Fig. 7-97 to 100 and 109). It stores the bile and discharges it into the duodenum when necessary. It also concentrates the bile by absorption through the folded mucosa. A gallbladder is **not present in the horse** (Fig. 7-100).

Pancreas

Like the liver the pancreas has both an **exocrine** and **endocrine** function (Fig. 7-112). Its exocrine product, the pancreatic juice is conveyed to the duodenum by one or more ducts, depending on the species. It contains three enzymes, one for the reduction of proteins, one for carbohydrates and one for fats. The endocrine part of the pancreas produces insulin, glucagon and somatostatin. (A more detailed description of the function of the pancreas can be found in physiology textbooks.)

The pancreas is located in the dorsal part of the abdominal cavity in close relationship to the proximal part of the duodenum (Fig. 7-110). It can be divided into three parts:

- Body of the pancreas (corpus pancreatis),
- Right lobe of the pancreas (lobus pancreatis dexter),
- Left lobe of the pancreas (lobus pancreatis sinister).

When hardened in situ it has the shape of a caudally open V and is either notched by the **portal vein** (incisura pancreatis) as it is in carnivores and ruminants or perforated (anulus pancreatis) as seen in the horse and pig (Fig. 7-110).

In carnivores the slender pancreas has the classic V-shaped form consisting of **two limbs,** that emerge from the body (Fig. 7-111). The **left limb** is shorter, but thicker than the right limb and runs within the origin of the greater omentum on the dorsal abdominal wall. The longer **right lobe** follows the descending duodenum within the mesoduodenum (Fig. 7-110).

In the pig the pancreas consists of a large body and a left lobe and a small right lobe, which surround the portal vein. In the horse the pancreas is **triangular** in outline with a large, compact body to which the short right lobe and a longer left lobe attach. It is perforated by the portal vein in the **pancreatic ring.** The pancreas of ruminants consists of a short body and right and left lobes. The right lobe is larger and follows the mesentery of the descending part of the duodenum. The

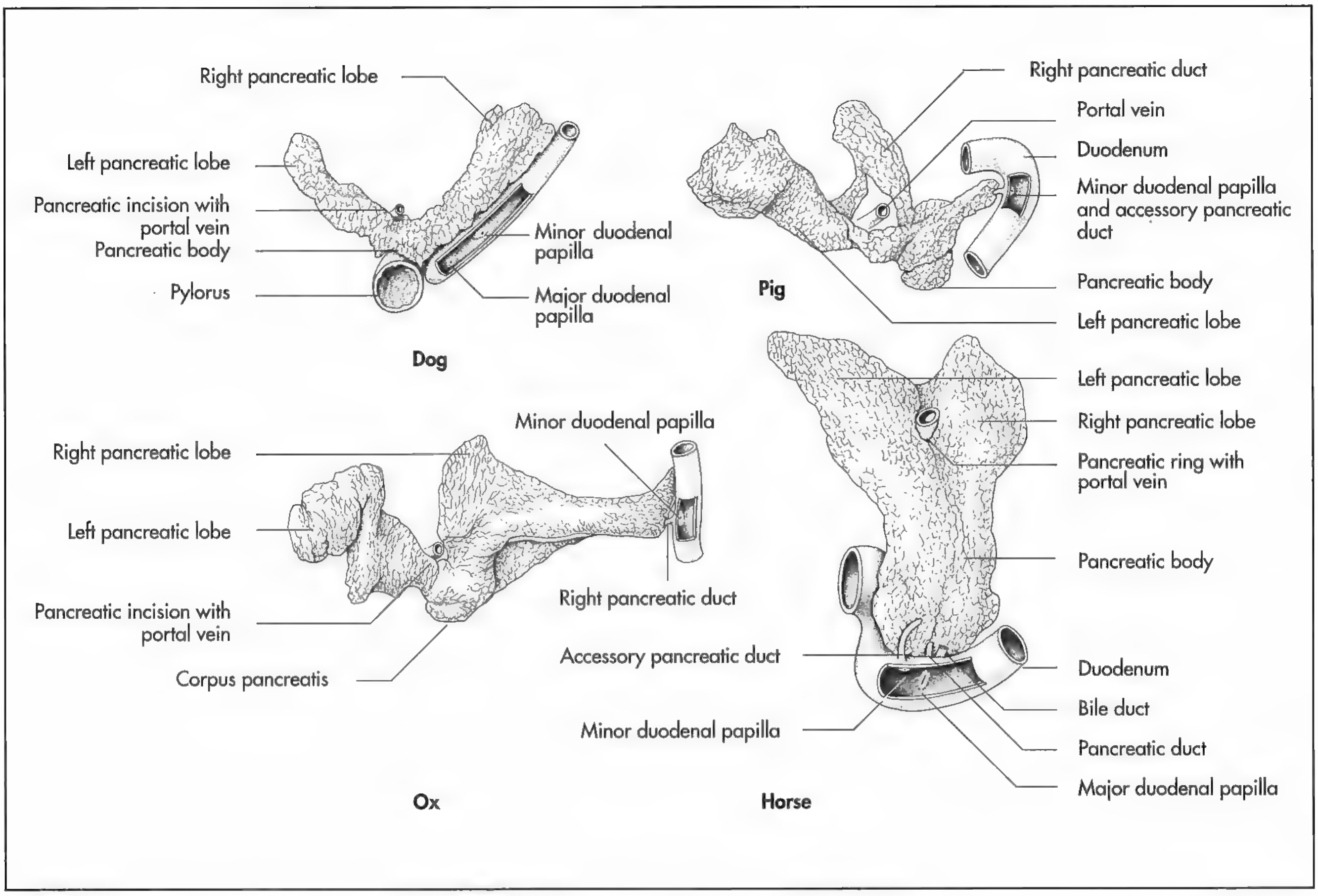

Fig 7-110. Pancreas of different domestic mammals, schematic (Nickel, Schummer, Seiferle, 1995).

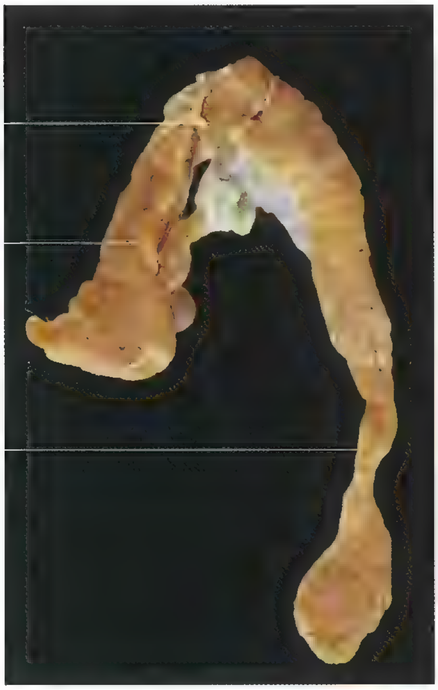

Fig 7-111. Pancreas of a dog, dorsal aspect.

Fig 7-112. Histological section of the pancreas of a cat.

portal vein passes over the dorsal border of the organ in the **pancreatic notch** (incisura pancreatis).

In conformity with the dual origin of the gland from dorsal and ventral primordia, some species have two pancreatic ducts. A **pancreatic duct** (ductus pancreaticus) commonly drains the part of the gland, that arises from the ventral primordium and opens into the duodenum together with or close to the bile duct on the **major duodenal papilla** (papilla duodeni major).

An **accessory duct** (ductus pancreaticus accessorius) emerges from the part of the pancreas that is formed by the dorsal primordium and opens on the opposite aspect of the duodenum on the **minor duodenal papilla** (papilla duodeni minor).

This anatomical arrangement is usually found in the dog and in the horse. In the other domestic mammals the excretory system is reduced to a single duct. The pancreatic duct usually survives in the cat and in the small ruminants, while in the pig and ox the accessory duct is still present. Since the two parts communicate inside the gland, the absence of one of the duct is of no significance.

Pancreatic duct system of the different species:

Cat: Pancreatic duct large,
small accessory pancreatic duct present in some individuals.
Dog: Pancreatic duct small, missing in some individuals,
accessory pancreatic duct large.
Pig: Accessory pancreatic duct.
Horse: Pancreatic duct large,
accessory pancreatic duct small.
Ox: Pancreatic duct extremely rare,
accessory pancreatic duct.
Small ruminants: Pancreatic duct,
some sheep with accessory pancreatic duct.

The pancreas is composed of **lobules** loosely united by small amounts of interlobular connective tissue, which produce a nodular surface with irregularly crenated margins. The exocrine component is by far the larger and the endocrine component consists of the **pancreatic islets,** cell accumulations, that are scattered between the exocrine acini (a more detailed description can be found in histology textbooks).

The **blood supply** of the pancreas is provided by the celiac and cranial mesenteric artery. The right lobe of the pancreas receives its blood supply from the **cranial pancreatoduodenal artery,** which is a branch of the **hepatic artery.** The left lobe and the body are vascularised by the **splenic artery** and the **caudal pancreaticoduodenal artery,** a branch of the cranial mesenteric artery. The veins are satellites to the arteries and eventually drain into the portal vein.

The pancreas receives a **parasympathetic** and **sympathetic nerve** supply. Parasympathetic fibres come from the dorsal **vagal trunk** (truncus vagalis dorsalis), **sympathetic fibres** from the **solar plexus** (plexus solaris).

The **lymphatics** of the pancreas drain into the **pancreaticoduodenal lymph nodes** (lymphonodi pancreaticoduodenales), which are part of the **celiac lymphatics** (lymphocentrum coeliacum).

Clinical terms related to the digestive system:
Glossistis, parodontitis, parontodosis, parotiditis, pulpitis, pharyngitis, tonsillitis, esophagitis, gastritis, ruminotomy, reticulitis, traumatis reticulitis, enteritis, duodenitis, jejunitis, ileitis, ileus, colitis, enterocolitis, hepatitis, pancreatitis etc.

8 Respiratory system (apparatus respiratorius)

H. E. König and H.-G. Liebich

The respiratory system is essential for gaseous exchange between air and blood. Respiration comprises both the transport of gases **to the cells** and the oxidative processes **within the cells.** The latter cannot be visualised with anatomical methods and is described in physiology.

Inspired air is filtered of small dust particles, moistened and warmed in the respiratory passages, which transfer air to and from the lungs. In the lungs, oxygen diffuses from the inspired air into the blood and carbon dioxide from the blood into the air. Inspired air consists of 20.9% oxygen, 0.03% carbon dioxide and 79.4% nitrogen. By contrast, expired air consists of 16% oxygen, 4% carbon dioxide and 80% nitrogen. The transport of these gases from the lungs to the cells and back is carried out by the **circulatory system.**

The respiratory system can be divided into the **respiratory passages** and sites of **gaseous exchange.**

The respiratory passages comprise the following organs:

- External nose (nasus externus),
- Nasal cavity (cavum nasi),
- Nasopharynx (pars nasalis pharyngis),
- Larynx,
- Trachea and
- Bronchi.

Sites of gaseous exchange within the lungs are:

- Respiratory bronchioli (bronchioli respiratorii),
- Alveolar ducts (ductus alveolares),
  Alveolar sacs (sacculi alveolares) and
- Alveoli (alveoli pulmonis).

Respiratory organs, which are located within the head (nose, paranasal sinuses, nasopharynx) are termed the **"upper respiratory tract"**, whereas the **"lower respiratory tract"** consists of the larynx, the trachea and the lungs.

Most of the **respiratory system** is lined by **respiratory mucosa** with a mucous-producing, pseudostratified epithelium. Some regions, which need to be more resistant, such as the nostrils, the larynx and the epiglottis, have a stratified squamous epithelium. The **olfactory region** in the caudal part of the nasal cavity has an **olfactory mucosa.** The sites of gaseous exchange have a single layer of squamous epithelial cells. (For a more detailed description see histology textbooks.)

Functions of the respiratory system

The respiratory system fulfils a variety of functions. The nose includes olfactory receptors, which provide environmental information, which can be used for orientation and to protect from harmful substances. The nasal cavity and conchae warm and moisten the air and filter foreign material. The larynx protects the entrance to the trachea and regulates the inspiration and expiration of air, and plays a major role in vocalisation assisted by other organs such as the tongue. All of the respiratory passages facilitate water and heat exchange, which is especially important in the dog. The trachea divides into the main stem bronchi, which then subdivide until the terminal divisions, the alveoli, the major site of gaseous exchange.

Upper respiratory tract

Nose (rhin, nasus)

The nose (greek: rhin, latin: nasus) (Fig. 8-1 and 2) consists of

- External nares and their associated nasal cartilages,
- Nasal cavity with the nasal meatus and conchae,
- Paranasal sinuses.

The nose is formed by the nasal bones dorsally, the maxillae laterally and the palatine processes of the incisive bones, the maxillae and the palatine bones ventrally. Caudally it is limited by the cribriform plate of the ethmoid bone. Ventrally it is continuous with the nasopharynx. The median septum is the rostral continuation of the crista galli of the ethmoid bone and consists of hyaline cartilage, the caudal part of which ossifies with age (Fig. 8-5 to 10) which divides the nasal cavity into the left and right sides.

Apex of the nose

The apex of the nose and the rostral portion of the mandible and maxilla form the muzzle. The form and size of the muzzle and the nature of the integument show considerable species differences. The integument around the nostrils is hairless and sharply demarcated from the unmodified skin in all domestic mammals other than the horse, where unmodified skin with

Fig. 8-1. External nose of a dog, frontal aspect.

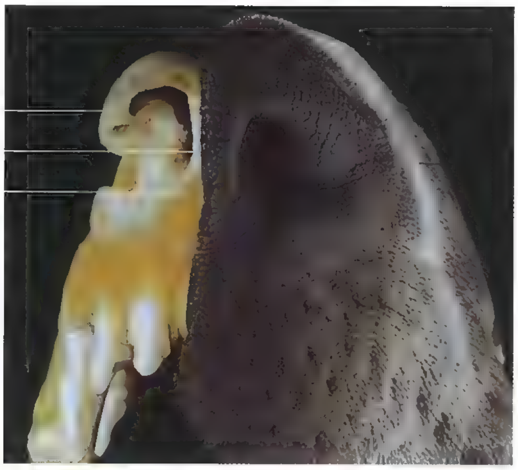

Fig. 8-2. External nose of a dog with exposed right nasal cartilages, frontal aspect (courtesy of Dr. R. Macher, Vienna).

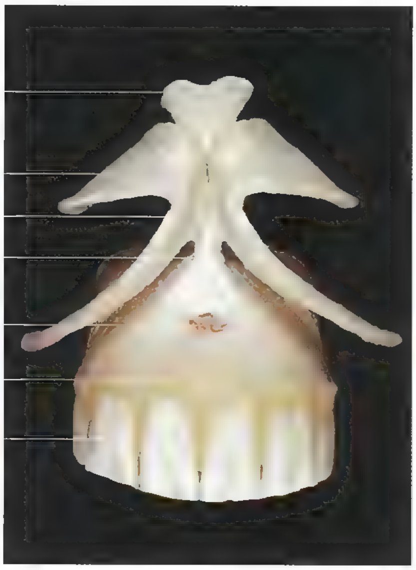

Fig. 8-3. Nasal cartilages of a horse, frontal aspect.

some tactile hairs surrounds the nostrils. In the ox the integument of the frontal region is modified to form the smooth hairless **nasolabial plate** (planum nasolabiale). The mucosa is covered by a stratified, cornified epithelium, which is moistened by serous glands, within the mucosa. In small ruminants, the dog and the cat the skin around the nostrils is also hairless. The **nasal plate** (planum nasale) is divided by a median groove, the philtrum, which continues ventrally to divide the upper lip (Fig. 8-1). The surface of the nasal plate of carnivores is moistened by secretion of the **lateral nasal gland,** situated within the **maxillary recess** (recessus maxillaris) and some smaller glands within the mucosa.

In the pig the disc-like movable point of the muzzle is called the **rostrum** or **snout.** The snout is supported by the rostral bone and covered by modified skin, which forms the **rostral plate** (planum rostrale) and includes tactile hairs and mucosal glands, which moisten the surface.

The surface of the nasal plate has numerous **fine grooves,** the pattern of which is thought to be individual and may be useful as means of identification, similar to fingerprints in humans.

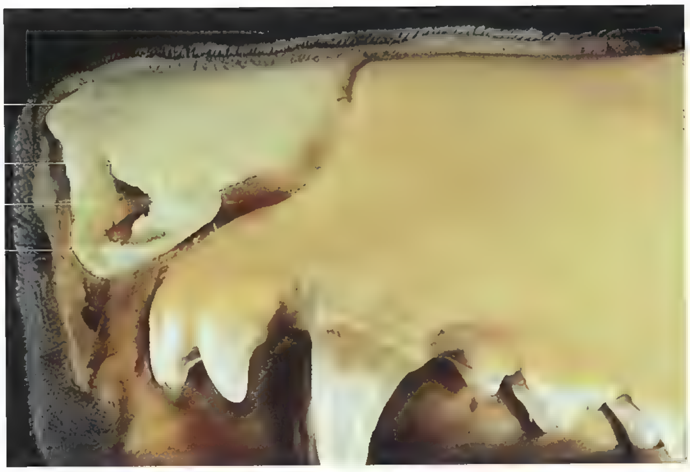

Fig. 8-4. Nasal cartilages of a dog, lateral aspect (courtesy of Dr. R. Macher, Vienna).

Fig. 8-5. Nasal cartilages of a horse, lateral aspect (courtesy of Dr. R. Macher, Vienna).

Nasal cartilages (cartilago nasi)

The external nares are supported by the nasal cartilages, which are variable in form, size and number depending on the species (Fig. 8-2 to 5). The lateral nasal cartilages are attached to the rostral end of the nasal septum from which they extend ventrally and dorsally (cartilago nasi lateralis dorsalis and cartilago nasi lateralis ventralis). They determine the form of the opening of the nostril. The dorsal and ventral lateral nasal cartilages are in contact with each other in all domestic species except the horse. Depending on the species several accessory nasal cartilages may arise from the lateral nasal cartilages.

In the horse the dorsal nasal cartilage does not project far and the ventral nasal cartilage is either indistinct or absent. Instead, the **alar cartilages** (cartilagines alares) which are divided into a **plate** (lamina) dorsally and a **horn** (cornu) support the large and widely spaced nostrils. The lateral walls of the nostrils are not supported by cartilage, thus the margins of the nostrils remain very mobile to allow the opening to be dilated, when necessary. The **alar cartilages** account for the characteristic comma shape, which divides the nostril into the ventral, so-called true nostril leading to the nasal cavity and the dorsal or false nostril, leading to a skin-lined **diverticulum** (diverticulum nasi) occupying the **nasoincisive notch** (incisura nasoincisiva). It is essential when passing a nasogastric tube to guide it ventrally.

In antiquity, foals had their false nostrils cut open, since it was thought that this would result in better performance, especially in military horses. This method is still practised today in the south eastern parts of Asia (Pakistan, Iran, Northern India). In the western world, nasal implants and cohesive skin strips are used to maintain the alar cartilages in full abduction in competition horses.

Nasal vestibule (vestibulum nasi)

The nostril forms the opening of the nasal cavity and surrounds the nasal vestibule. In the horse and donkey, the integument continues within the nasal cavity, and forms a sharp demarcation with the nasal mucosa. In the horse, the **nasal puncta** of the **nasolacrimal duct** is located on the ventral floor of the vestibule, near to this mucosal transition. In other species it is

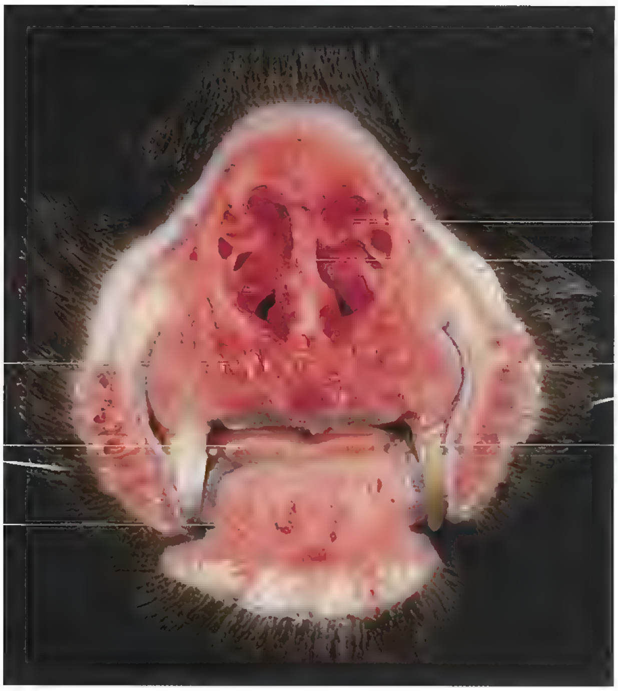

Fig. 8-6. Transverse section of the head of a dog at the level of the canine tooth, frontal aspect (courtesy of PD Dr. J. Maierl, Munich).

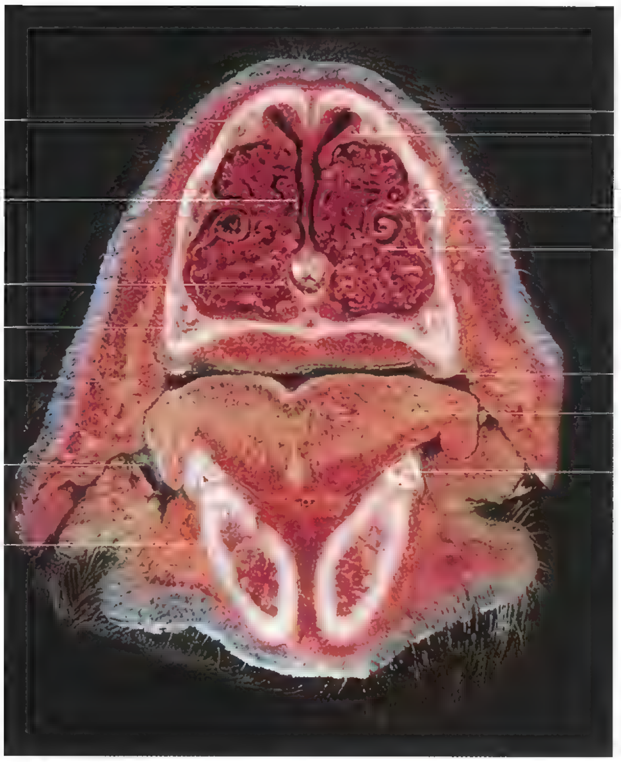

Fig. 8-7. Transverse section of the head of a dog at the level of the second premolar, frontal aspect (courtesy of PD Dr. J. Maierl, Munich).

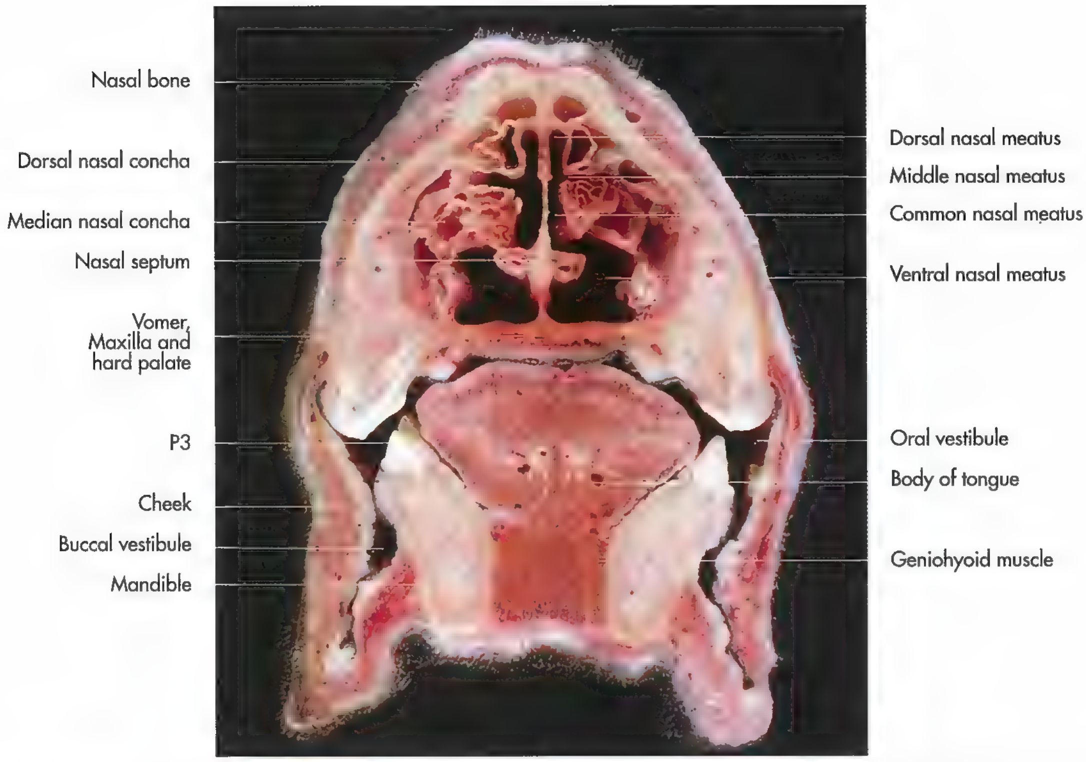

Fig. 8-8. Transverse section of the head of a dog at the level of the third premolar, frontal aspect (courtesy of PD Dr. J. Maierl, Munich).

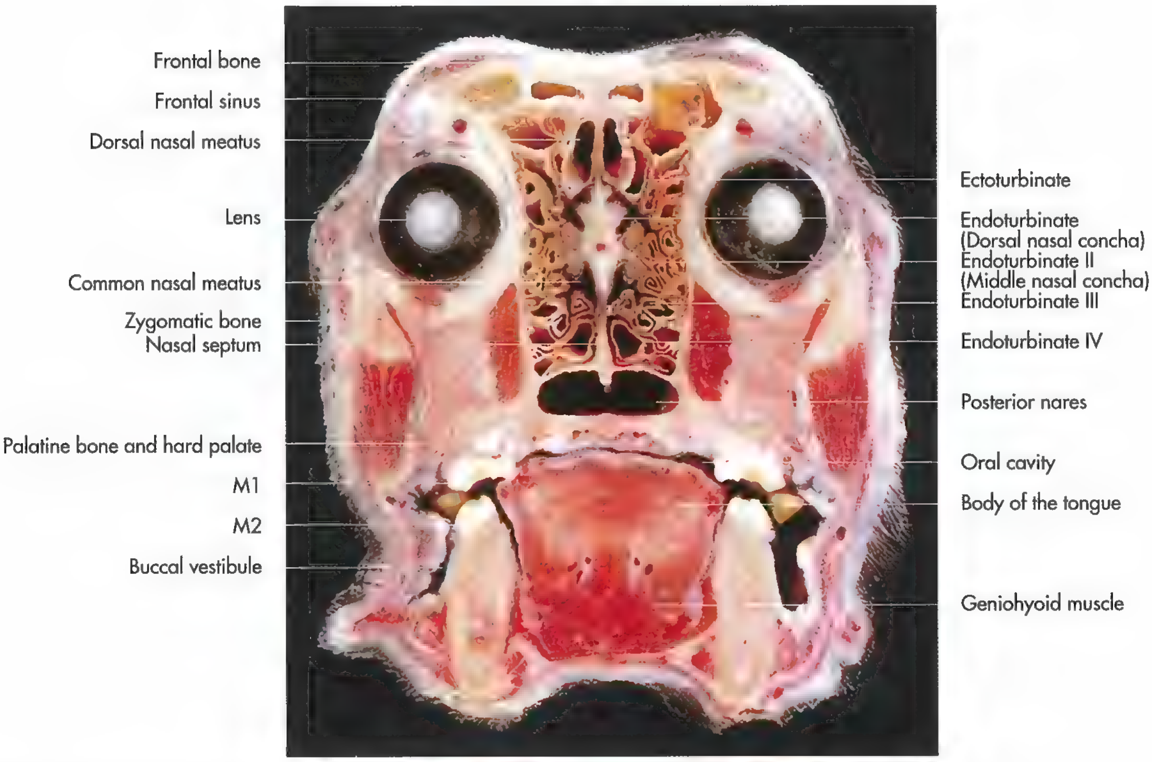

Fig. 8-9. Transverse section of the head of a dog, frontal aspect (courtesy of PD Dr. J. Maierl, Munich).

Fig. 8-10. Paramedian section of the head of a dog, medial aspect (courtesy of PD Dr. J. Maierl, Munich).

located more caudally, occasionally with more than one opening. In the dog the much smaller and less distinct openings of the serous lateral nasal glands also discharge in this region.

Nasal cavities (cava nasi)

The nasal cavity extends from the nostrils to the **cribriform plate of the ethmoid bone,** and is divided by the **nasal septum** into right and left sides. The **nasal conchae** (conchae nasales) project into the interior of the nasal cavity and serve to increase the respiratory surface area (Fig. 8-6 to 10). In animals with highly developed olfactory senses, such as the dog, the nasal conchae are more comples, further increasing the olfactory surface area. This increase in surface area, together with a higher number of olfactory receptor cells accounts for the excellent olfactory sense of the dog compared to humans. Vascular plexii underlie the mucosa and are fomed by multiple anastomsing vessels.

Caudoventrally the nasal cavity communicates with the nasopharynx through the choanae.

Nasal conchae (conchae nasales)

The nasal conchae are cartilagenous or ossified scrolls covered with nasal mucosa that occupy most of the nasal cavity (Fig. 8-6 to 10). They have a complicated and species specific arrangement.

The **first endoturbinate** (endoturbinale I) is the longest and most dorsal turbinate and extends furthest into the nasal cavity. It forms the osseous base of the **dorsal nasal conchae** (concha nasalis dorsalis). The **second endoturbinate** (endoturbinale II) is adjacent to the first and forms the bony part of the **middle nasal conchae** (concha nasalis media). Subsequent turbinates are reduced in size, with the exception of the dog, in which the second to fourth endoturbinates are especially well-developed. While the dorsal and middle nasal concha are formed by the endoturbinates, the **ventral nasal concha** (concha nasalis ventralis) is part of the **maxilla.**

(The osseous structure of the conchal bones (ossa conchae) are described in detail in chapter 1.)

Nasal meatuses (meatus nasi)

The major conchae divide the nasal cavity into a series of clefts and meatus, which branch out from a common meatus near the nasal septum. There are **three nasal meatuses** in the domestic mammals (Fig. 8-8 and 9):

- Dorsal nasal meatus (meatus nasi dorsalis),
- Middle nasal meatus (meatus nasi medius),
- Ventral nasal meatus (meatus nasi ventralis).

The **dorsal nasal meatus** is the passage between the roof of the nasal cavity and the dorsal nasal concha. It leads directly to the fundus of the nasal cavity and channels air to the olfactory mucosa.

The **middle nasal meatus** is between the dorsal and the ventral nasal conchae and communicates with the paranasal sinuses.

Ventral nasal meatus is the main pathway for airflow leading to the pharynx and is situated between the ventral nasal conchae and the floor of the nasal cavity.

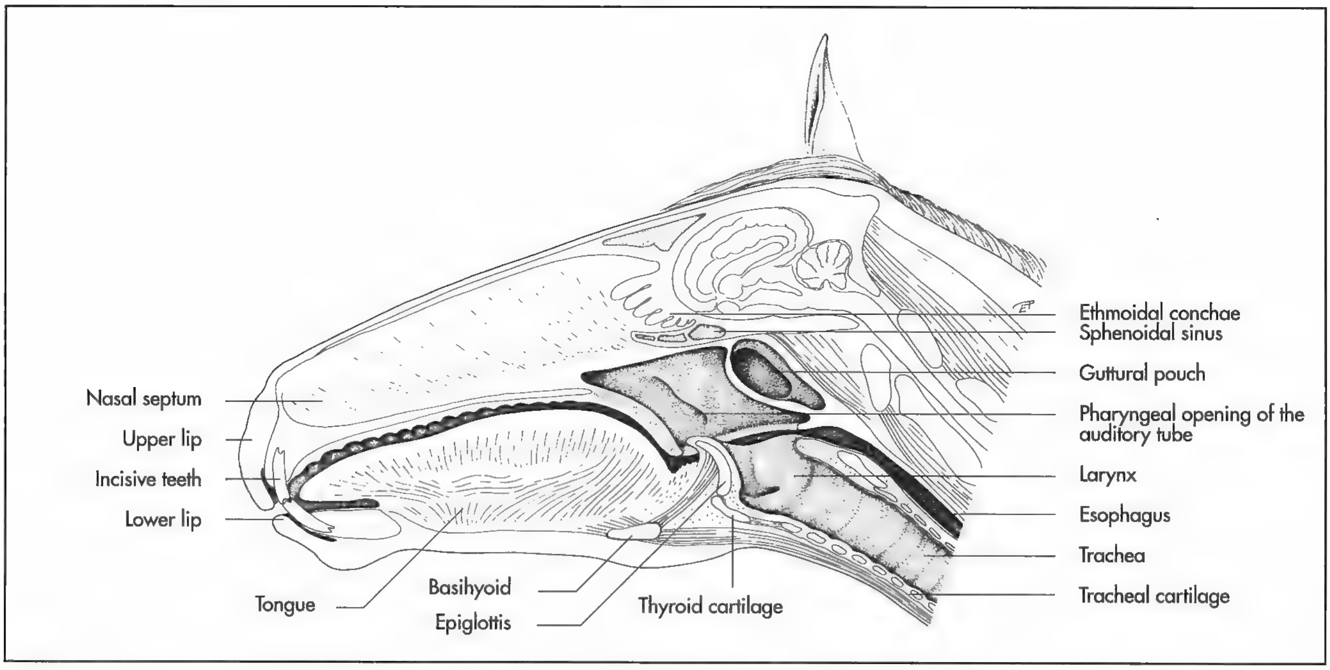

Fig. 8-11. Median section of the head of the horse, illustrating the pharynx and larynx, schematic.

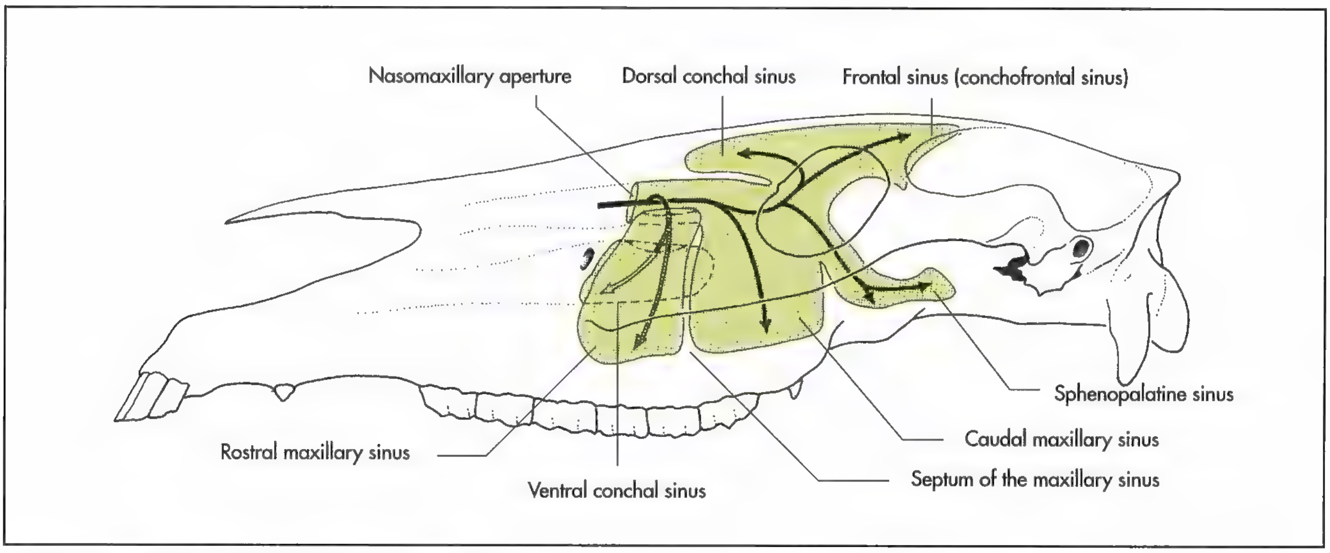

Fig. 8-12. Paranasal sinuses of the horse, schematic.

The **common nasal meatus** (meatus nasi communis) is the longitudinal space on either side of the nasal septum. It is communicate with all the other nasal meatus.

The pharynx can be accessed by the passage of nasogastric tubes and endoscopes by their passage through the widest point, between the ventral and common meatus.

Paranasal sinuses (sinus paranasales)

The **paranasal sinuses** are diverticula of the nasal cavity, which form air-filled cavities between the external and internal lamina of the bones of the skull. (The osseous structure of the paranasal sinuses are described in detail in chapter 1.) They undergo significant expansion after birth and continue to increase in size with advancing age. They are particularly well-developed in the ox and the horse and account for the conformation of the head in these species. The paranasal sinuses are hypothesised to provide thermal and mechanical protection to the orbit, nasal cavity and cranial cavities, and also enlarge the areas for muscular attachment without considerably increasing the weight of the skull.

The paranasal sinuses are lined by **respiratory mucosa,** which is extremely thin and poorly vascularised. This is thought to account for the poor healing capacity of this area. Treatment is complicated due to the narrowness and locations of the openings, which makes them prone to blockage when

Fig. 8-13. Skull of a horse with hyoid bone and larynx.

the mucosa is thickened by inflammation. The following paired paranasal sinuses can be found in the skull of domestic mammals:

- Maxillary sinus (sinus maxillaris),
- Frontal sinus (sinus frontalis),
- Palatine sinus (sinus palatinus),
- Sphenoidal sinus (sinus sphenoidalis),
- Lacrimal sinus (sinus lacrimalis) in the pig and ruminants,
- Dorsal conchal sinus (sinus conchae dorsalis) and ventral conchal sinus (sinus conchae ventralis) in the pig, ruminants and horse and
- Cellulae ethmoidales in the pig and ruminants.

The **maxillary sinus** is contained within the caudal part of the maxilla. In the horse a bony septum divides the maxillary sinus in a **smaller rostral compartment** (sinus maxillaris rostralis) and a **larger caudal one** (sinus maxillaris caudalis). The floor of the maxillary sinuses is indented by the dental alveoli for the last three cheek teeth. Since only a thin bone plate separates the tooth roots from the paranasal sinus, periapical infection can easily penetrate the bone and cause sinusitis. On the other hand an entry into the sinus by trepanation allows access to the teeth for treatment of dental diseases.

The sagittally orientated infraorbital canal projects into the maxillary sinuses and divides them into a medial and a lateral compartment. Both compartments share a slit-like opening towards the middle nasal meatus, the **nasomaxillary aperture** (apertura nasomaxillaris). The rostral maxillary sinus communicates with the ventral conchal sinus through the **conchomaxillary opening** (apertura conchomaxillaris). The caudal maxillary sinus communicates directly or indirectly with all the other paranasal sinuses. This anatomical arrangement accounts for the spread of infection throughout the paranasal sinuses in the horse.

The maxillary sinus of carnivores is better termed the **maxillary recess** (recessus maxillaris), since it is a diverticulum of the nasal cavity at the level of the medial nasal concha rather than a real air-filled cavity between the internal and external laminae of the bones of the skull.

The **frontal sinus** is contained within the frontal bone and usually communicates with the middle nasal meatus. In the horse it is continuous with the dorsal conchal sinus and therefore referred to as the **conchofrontal sinus** (sinus conchofrontalis). The caudal maxillary sinus communicates with the conchofrontal sinus through the wide **frontomaxillary opening** (apertura frontomaxillaris).

In the pig and the ox the frontal sinus is divided into several compartments and extends to the nuchal region caudally. In ruminants it extends into the cornual process of the frontal bone, which accounts for the high incidence of inflammation of the frontal sinus after surgical dehorning.

In the horse the **palatine** and **sphenoid bones** are also pneumatised. The union of the palatine and the sphenoidal sinus results in the combined sphenopalatine sinus, which communicates with the caudal maxillary sinus (Fig. 8-12). The optical chiasma is located just dorsal to the sphenoid sinus, separated from the latter by a extremely thin bony plate only. Sinusitis can thus easily spread over onto the optical nerve resulting in impaired vision.

Lower respiratory tract

Larynx

The larynx is a bilaterally symmetrical, tube-shaped musculocartilagenous organ that connects the pharynx to the trachea (Fig. 8-11, 13 and 15 to 18). It protects the entrance to the trachea thus preventing aspiration of foreign material into the lower respiratory tract. It is also important in vocalisation. The

Fig. 8-14. Radiograph of the head of a cat (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

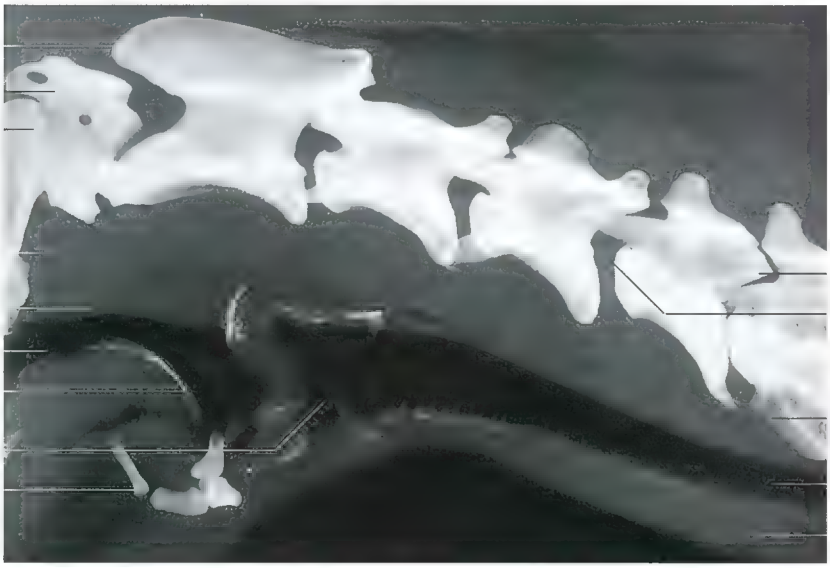

Fig. 8-15. Radiograph of the larynx and the cervical spine of a cat (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

walls of the larynx are formed by the laryngeal cartilages and their connecting muscles and ligaments, which join the larynx to the hyoid apparatus rostrally and to the trachea caudally. The laryngeal walls enclose the **cavity of the larynx** (cavum laryngis), the lumen of which is constricted by the **vocal folds** (plicae vocales). During swallowing the epiglottis tilts backward to partially cover the rostral opening of the larynx. Caudally, the laryngeal cavity is continuous with the lumen of the trachea.

Most of the laryngeal cavity is lined by stratified squamous epithelium, although respiratory mucosa is present caudally.

Cartilages of the larynx (cartilagines laryngis)

The skeleton of the larynx is composed of the following bilaterally symmetrical laryngeal cartilages (Fig. 8-16 to 18).

- Epiglottic cartilage (cartilago epiglottica) forming the base of the epiglottis,
- Thyroid cartilage (cartilago thyroidea),
- Arytenoid cartilages (cartilagines arytenoideae) and
- Cricoid cartilage (cartilago cricoidea).

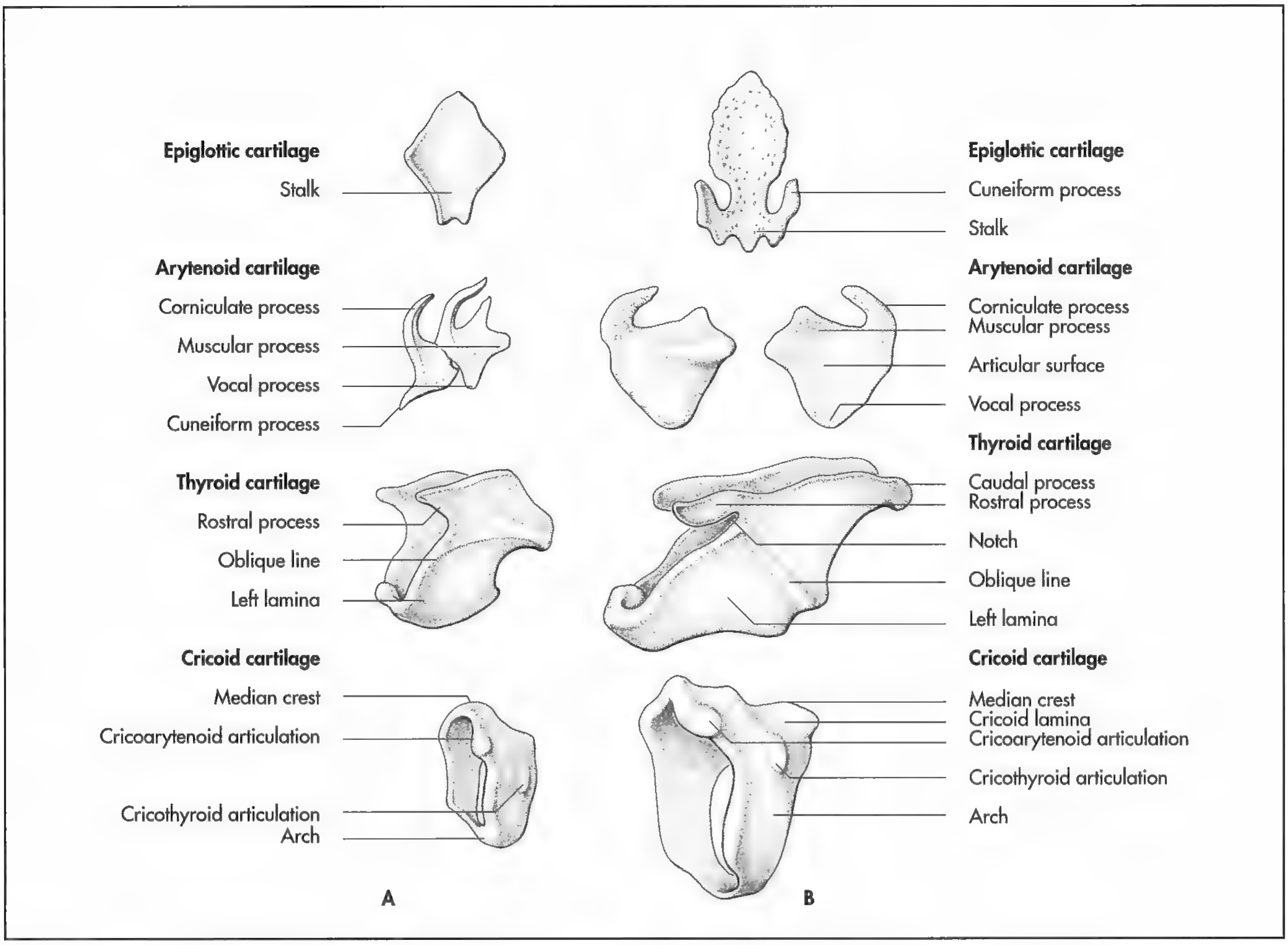

Fig. 8-16. Laryngeal cartilages of the dog **(A)** and the horse **(B)**, schematic.

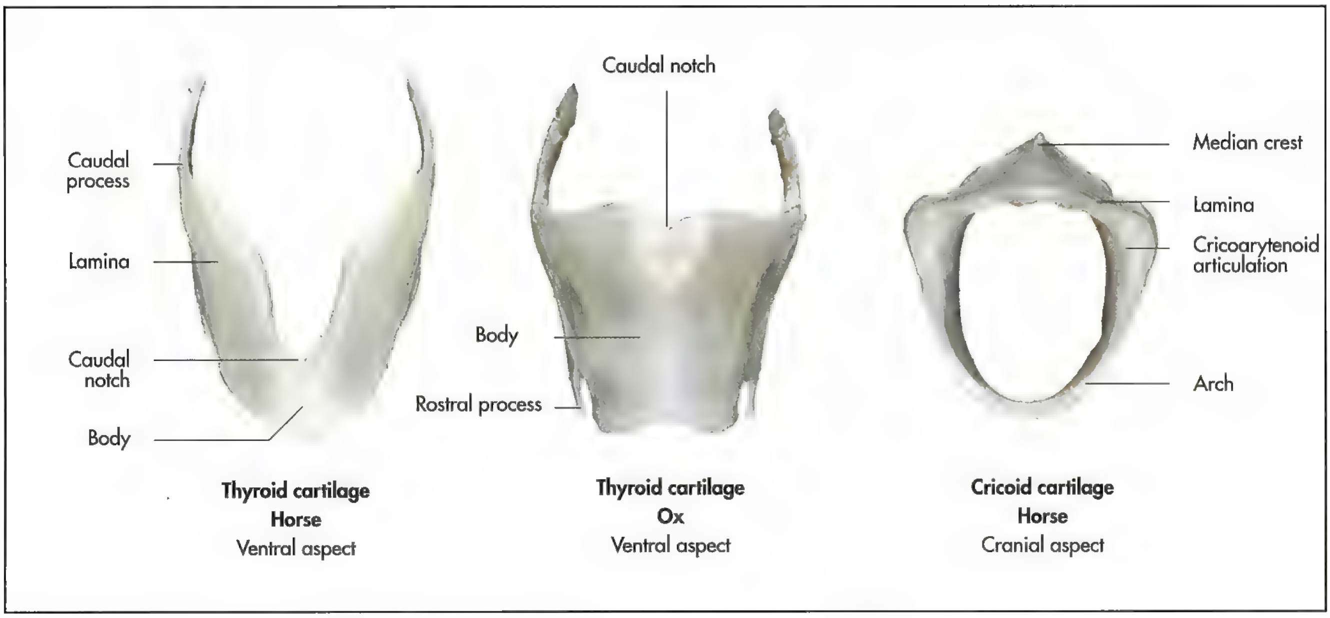

Fig. 8-17. Thyroid and cricoid cartilages of a horse and an ox.

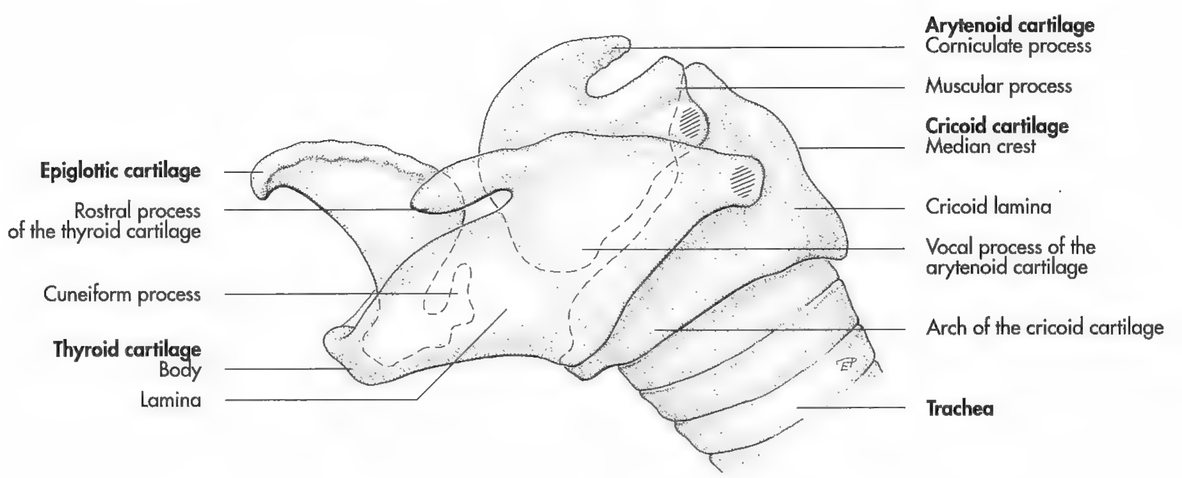

Fig. 8-18. Laryngeal cartilages of the horse, schematic.

Epiglottis

The epiglottic cartilage forms the base of the epiglottis (Fig. 8-16 and 18). The epiglottis resembles a leaf with a small **stalk** (petiolus) and a **large blade.** Its free apex points rostrally and is sharp-pointed in carnivores and the horse and more rounded in ruminants and the pig. The stalk is connected to the thyroid cartilage and the blade projects dorsorostrally behind the soft palate at rest (retrovelar position). During swallowing it tilts caudally to cover the entrance to the laryngeal cavity. The epiglottic cartilage consists of **elastic cartilage. Cuneiform processes** (processus cuneiformes) are present in some animals on each side of the base of the epiglottis, projecting dorsally. They may be free or fused with the epiglottis or the arytenoid cartilages.

Thyroid cartilage (cartilago thyroidea)

The thyroid cartilage contains **hyaline cartilage,** which may ossify with advancing age and forms the lateral walls and the floor of the larynx (Fig. 8-16 to 18). It has two lateral **plates** (lamina lateralis dextra and sinistra) and a ventral **body** (corpus). Each lamina is expanded dorsally to form rostral and caudal processes (cornu rostralis et caudalis). The rostral process articulates with the hyoid bone, the caudal process with the cricoid cartilage. In the horse the rostral process is separated from the plate by a **notch** (fissura thyroidea) (Fig. 8-16).

In the horse the ventral part of the thyroid cartilage is reduced to a **narrow bridge** rostrally to which the stalk of the epiglottis attaches. This leaves a large notch in the floor of the larynx caudal to it, which is covered by soft tissues only, thus providing convenient access for laryngeal surgery.

Arytenoid cartilage (cartilagines arytaenoideae)

The arytenoid cartilages are formed of **hyaline cartilage** and are the only **paired laryngeal cartilages,** which meet dorsally to cover the notch left open by the lamina of the thyroid cartilage, thus forming the major part of the roof of the larynx. A small hyaline **interarytenoid cartilage** (cartilago interarytenoidea) may be found between the arytenoid cartilages dorsally.

The arytenoid cartilages have the form of a triangle from which three processes radiate. A corniculate process extends dorsomedially from the rostral angle of the triangle, a vocal process, to which the vocal fold attaches projects ventrally into the laryngeal cavity and a muscular process extends laterally and provides attachment to the dorsal cricoarytenoid muscle. A caudal facet articulates with the arytenoid plate.

Cricoid cartilage (cartilago cricoidea)

The cricoid cartilage forms a complete ring at the caudal end of the larynx (Fig. 8-16). It has the shape of a signet ring with an expanded **plate** (lamina) dorsally and a narrower ventral arch. The dorsal plate articulates with the arytenoid cartilages, while the ventral arch articulates with the caudal processes of the thyroid cartilage. The ventral arch is very similar to the caudally succeeding tracheal cartilages. Like the thyroid cartilage it is formed of **hyaline cartilage,** which may also ossify with age.

Laryngeal cavity (cavum laryngis)

The inlet to the **laryngeal cavity** (aditus laryngis) is bound by the epiglottis, the **aryepiglottic fold** (plica aryepiglottica) and the arytenoid cartilages (Fig. 8-19). The laryngeal inlet leads into the wide antechamber or **vestibule of the larynx** (vestibulum laryngis).

The middle portion is known as the glottis and consists of the paired arytenoid cartilages dorsally (pars intercartilaginea) and the paired vocal folds ventrally (pars intermembranacea), that form a narrow passageway into the pharynx, which is called the **glottic cleft** (rima glottis) (Fig. 8-23). Caudal to the glottis the lumen becomes wider to form the **infra-**

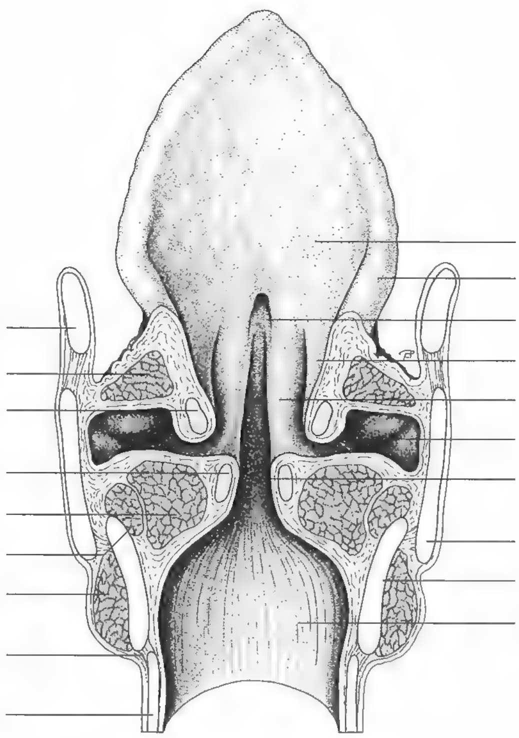

Fig. 8-19. Dorsal section of the larynx of the horse, schematic (Budras and Röck, 1994).

glottic cavity (cavum infraglotticum) which extends to the trachea.

In the horse and the dog, a **lateral laryngeal ventricle** (ventriculus laryngis lateralis) is formed on each side by an outpouching of the laryngeal mucosa. The entrance to the lateral ventricles is located between the vestibular fold rostrally and the vocal fold caudally (Fig. 8-19). In the pig and horse an unpaired **median outpouching** (recessus laryngis medianus) of the floor of the laryngeal vestibule is present caudal to the epiglottis (Fig. 8-19).

In the pig the vocal fold is split into two portions with a small lateral laryngeal ventricle between them.

Articulations and ligaments of the larynx

All articulations between the different laryngeal cartilages are synovial joints with the exception of the articulation between the epiglottis and the rest of the larynx. There is also a synovial articulation between the thyroid and thyrohyoid cartilages. The epiglottis is joined to the thyroid cartilage by **elastic fibres** and to the arytenoid cartilages by **elastic membranes.**

The synovial articulations between the cricoid cartilage and the arytenoid cartilages (articulatio cricoarytaenoidea) allow abduction and adduction to the arytenoid cartilages, which results in expansion of the glottic cleft during inspiration and narrowing of the glottic cleft during expiration (Fig. 8-23).

In some horses, hemiplegia of the **left recurrent laryngeal nerve** results in incomplete abduction of the the left arytenoid cartilage and thus the left vocal fold does not abduct sufficiently, thus producing a **"roaring"** sound during inspiration (Fig. 8-24). The aetiopathogenesis of this condition is unknown and results in palpable atrophy of the dorsal cricoarytenoid muscle, the abductor of the arytenoid cartilage.

The dorsocaudal angle of the thyroid cartilage articulates with the lamina of the cricoid cartilage (articulatio cricothyroidea) (Fig. 8-20 and 21), the ventrocaudal part of the thyroid cartilage is connected to the ventral arch of the cricoid cartilage by the cricothyroid ligament. In the horse the cricothyroid ligament covers the wide caudal thyroid notch and has to be dissected to get access to the laryngeal cavity during surgery.

The **vocal ligament** (ligamentum vocale) extends between the vocal process of the arytenoid cartilages and the body of the thyroid cartilage on either side. It forms the basis of the **vocal fold** (plica vocalis) (Fig. 8-19). In animals with a vestibular fold a vestibular ligament is present rostral to the vocal ligament. The larynx is joined to the basihyoid bone rostrally by the thyreohyoid membrane and to the first tracheal cartilage caudally by the cricotracheal ligament.

Muscles of the larynx

There are several groups of muscles, which are related to the larynx:

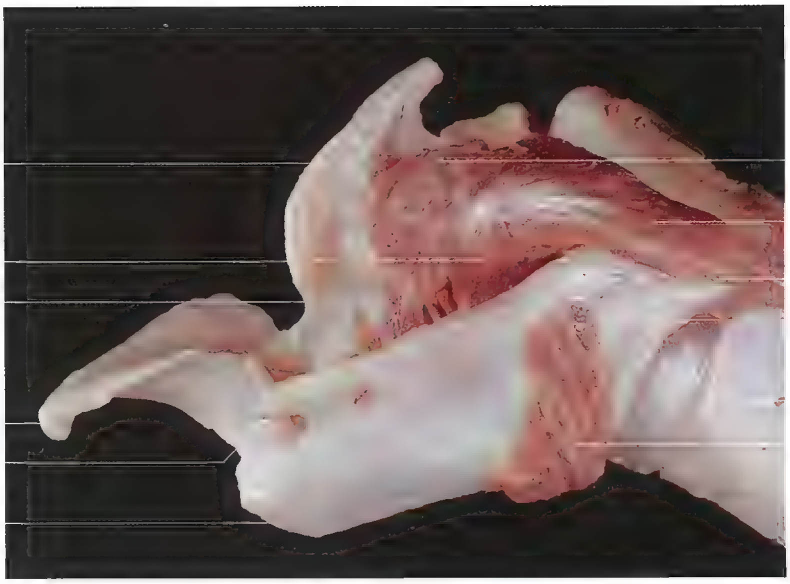

Fig. 8-20. Larynx of a horse, demonstrating the laryngeal muscles (courtesy of Dr. R. Macher, Vienna).

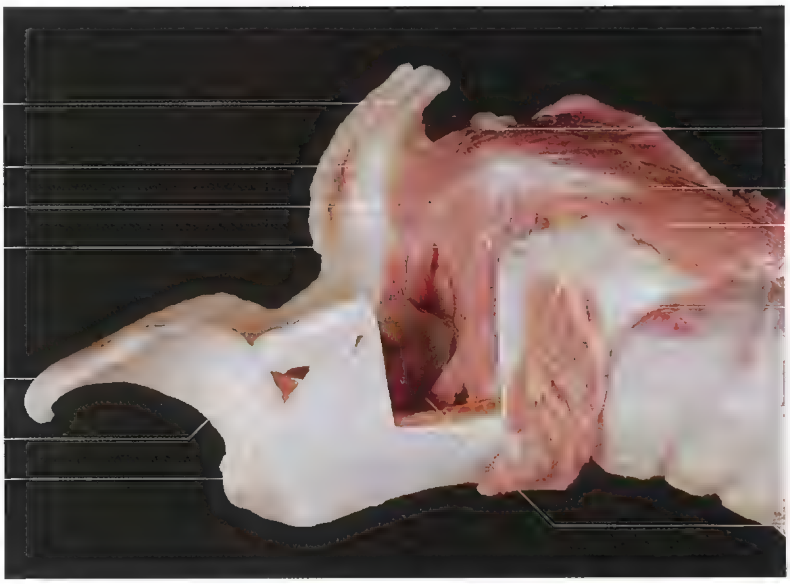

Fig. 8-21. Larynx of a horse, thyroid cartilage partly removed (courtesy of Dr. R. Macher, Vienna).

- Extrinsic muscles pass between the external surface of the larynx and the pharynx, hyoid bone, sternum and tongue,
- Intrinsic muscles pass between the laryngeal cartilages.

The extrinsic laryngeal muscles comprise the long muscles of the hyoid bone, which originate from the sternum and draw the larynx caudally and the muscles, which originate from the hyoid apparatus and draw the larynx rostrally. These muscles are described in detail in chapter 2.

The intrinsic laryngeal musculature consists of a set of small paired muscles that join the laryngeal cartilages (Fig. 8-20 to 22). They widen and narrow the glottic cleft and tense and relax the vocal folds (Fig. 8-23). The intrinsic laryngeal musculature are:

- Cricothyroid muscle (m. cricothyroideus),
- Dorsal cricoarytenoid muscle (m. cricoarytaenoideus dorsalis),
- Lateral cricoarytenoid muscle (m. cricoarytaenoideus lateralis),
- Transverse arytenoid muscle (m. arytaenoideus transversus) and
- Thyroarytenoid muscle (m. thyroarytaenoideus).

The **cricothyroid muscle** extends between the lateral surface of the thyroid lamina and the cricoid arch. It is the only laryngeal muscle, which is innervated by the **cranial laryngeal nerve,** while all the other muscles of this group are innervated by branches of the **caudal (recurrent) laryngeal nerve.** On contraction, it tenses the vocal folds.

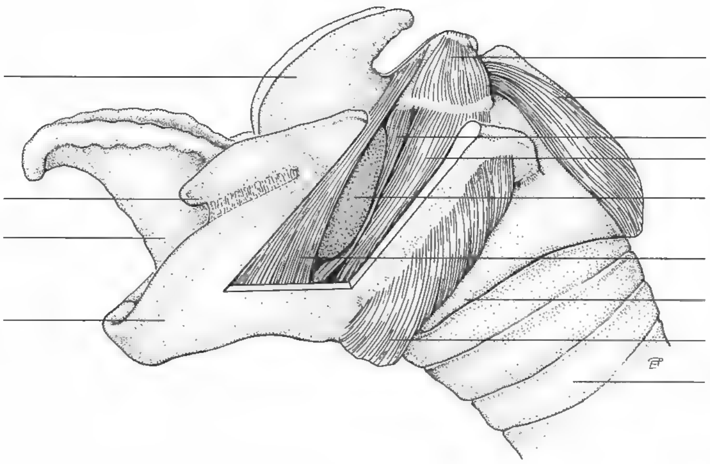

Fig. 8-22. Larynx of the horse, thyroid cartilage partly removed, schematic.

The **dorsal cricoarytenoid muscle** is the main abductor of the vocal folds, thus widening the glottic cleft. It arises from the dorsal surface of the cricoid lamina and its fibres converge rostrally to insert on the muscular process of the arytenoid cartilages. The lateral cricoarytenoid muscle extends between the cricoid arch and the muscular process of the arytenoid cartilages. Contraction of this muscle narrows the glottic cleft.

The **transverse arytenoid muscle** is a relatively weak muscle that connects the muscular processes of one arytenoid cartilage with its contralateral counterpart. It is interrupted by a median tendineous intersection. It adducts the two arytenoid cartilages, thus narrowing the glottic cleft.

The **thyroarytenoid muscle** arises from the base of the epiglottis and the thyroid cartilage and passes caudodorsally to insert on the muscular and vocal processes of the arytenoid cartilages. In the horse and the dog it is divided into the ventricular and the vocal muscles, which run with the like named folds. They increase the tension of the vocal folds and narrow the glottic cleft.

Functions of the larynx

During swallowing the epiglottis protects the lower respiratory tract against aspiration of foreign material. (For a detailed description of the swallowing mechanism see chapter 7.)

The glottis closes **(expiration)** and opens **(inspiration)** rhythmically during respiration. Widening of the glottis is mainly a result of the contraction of the dorsal cricoarytenoid muscles, narrowing is achieved by contraction of the lateral cricoarytenoid muscles, both of which are innervated by the caudal (recurrent) laryngeal nerves. These movements can be visualised by performing laryngoscopy. In a horse with paralysis of the left recurrent laryngeal nerve the abduction of the left side is reduced.

Closure of the glottis also occurs during coughing and sneezing: build-up pressure against a closed glottis allows for a forceful expulsion when the air is released. Sustained closure with elevation of the intrathoracic pressure is used when straining during defecation, micturition and parturition.

Another important function of the larynx is **vocalisation.** In the cat purring sounds are produced by the rapid contractions (20–30 per second) of the vocal muscles, assisted by fast twitching of the diaphragm. This causes vibration of the vocal folds during inspiration and expiration.

Blood supply and innervation of the larynx

The blood supply of the larynx is provided by the laryngeal branch (ramus laryngeus) of the **cranial thyroid artery** (a. thyroidea cranialis), which extends from the cranial end of the **common carotid artery** (a. carotis communis). The laryngeal branch of the cranial throids artery branches to form a muscular branch, which supplies the laryngeal muscles, and continues through the thyroid notch to supply the vocal and vestibular muscles and the laryngeal mucosa.

The larynx is innervated by branches of the **vagus nerve.** The **cranial laryngeal nerve** (n. laryngeus cranialis) branches from the vagus nerve caudal to the pharyngeal branch at the level of the **distal ganglion of the vagus** (ganglion distale nervi vagi, formerly called nodose ganglion). This ganglion is not visible macroscopically in all individuals, but can be found histologically.

The **cranial laryngeal nerve** divides into an external and internal branch. The external branch innervates the constrictors of the pharynx and the cricothyroid muscle. In some animals, it communicates with the caudal laryngeal nerve. The internal branch passes over the thyroid notch to the inside of the larynx, where it innervates the mucosa. The internal branch usually anastomoses (ramus communicans) with the caudal laryngeal nerve.

The **caudal laryngeal nerves** (n. larngeus caudalis) supply motor innervation to all of the intrinsic muscles of the larynx except the cricothyroid muscle. It originates in the thorax

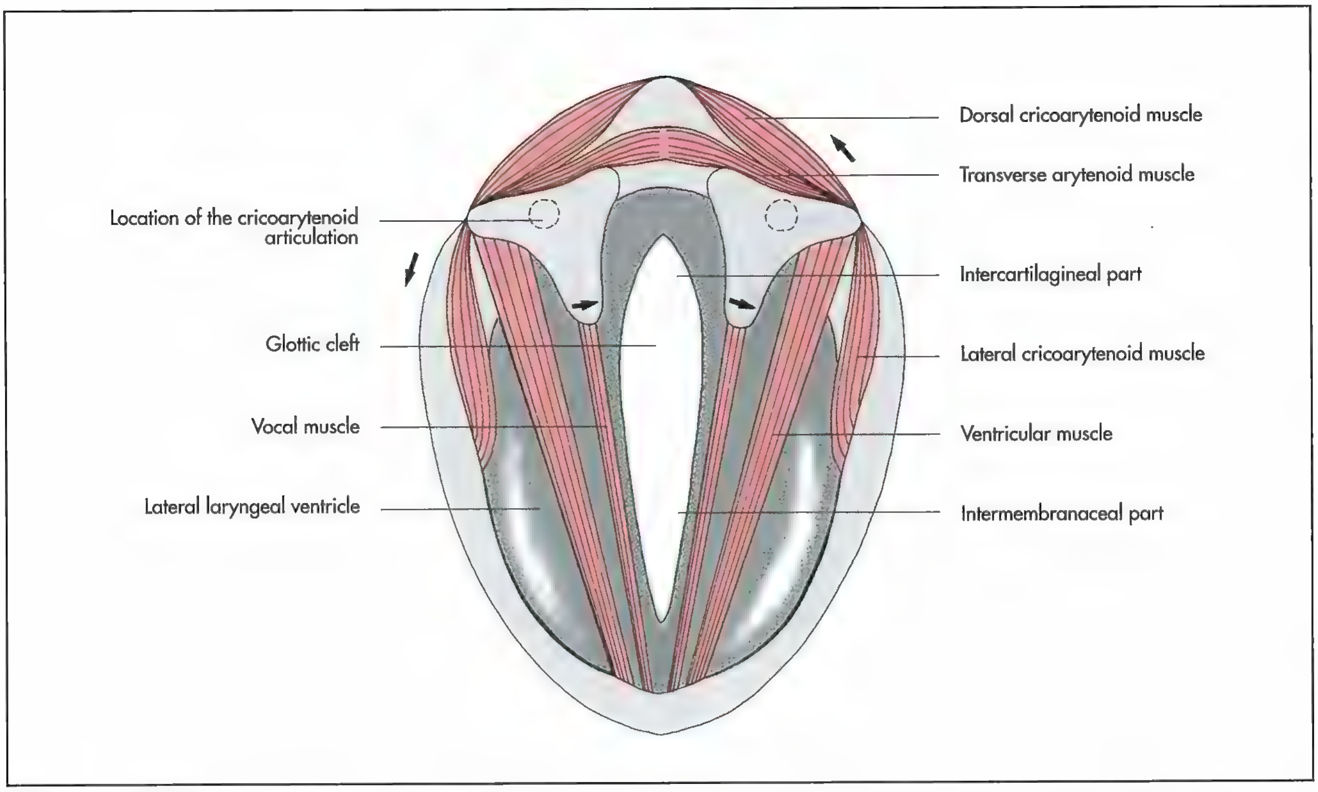

Fig. 8-23. Cross section of the larynx of the horse, schematic. Arrows indicating the narrowing and expansion of the glottic cleft (Budras and Röck, 1994).

by leaving the vagus. During embryonic development of the heart the left and right caudal laryngeal nerves are drawn caudally to pass around the aorta on the left and around the costocervical artery on the right before running cranially to the larynx as the **recurrent nerves** (nn. laryngei recurrentes). Hemiplegia of the left recurrent laryngeal nerve in the horse may relate to mechanical damage as this nerve passes around the aorta.

The **caudal (recurrent) laryngeal nerve** is of clinical importance in the horse, since **paralysis** (most commonly) of the left recurrent laryngeal nerve results in a stertorous sound produced at inspiration in affected animal. The term "roaring" is applied to this condition and affected animals are known as **"roarers"**. The sound is caused by the air flow passively vibrating a lax, adducted vocal fold. The laxity results from paralysis of the dorsal cricoarytenoid muscle, the abductor of the arytenoid cartilage and vocal fold, although other muscles may be also involved, especially in more advanced stages of the disease. Several theories regarding the aetiopathogenesis of the disease have been advanced. The asymmetry in incidence directs attention to the differences in the course and relations of the left versus the right recurrent laryngeal nerve. The left nerve loops around the aortic arch, which may cause mechanical damage to the nerve by the pulsing aorta. The close proximity of the tacheobronchial lymph nodes may also be involved in the aetiopathogenesis of this condition, whereby infalmmation may result in a distal axonopathy.

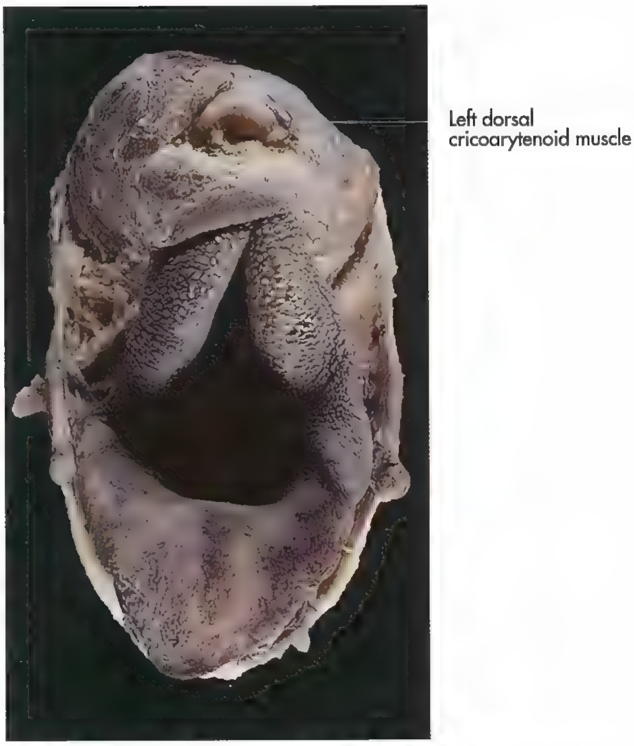

Fig. 8-24. Larynx of a horse suffering from hemiplegia of the left recurrent laryngeal nerve, rostral aspect (courtesy of Dr. Susanne Vrba, Vienna).

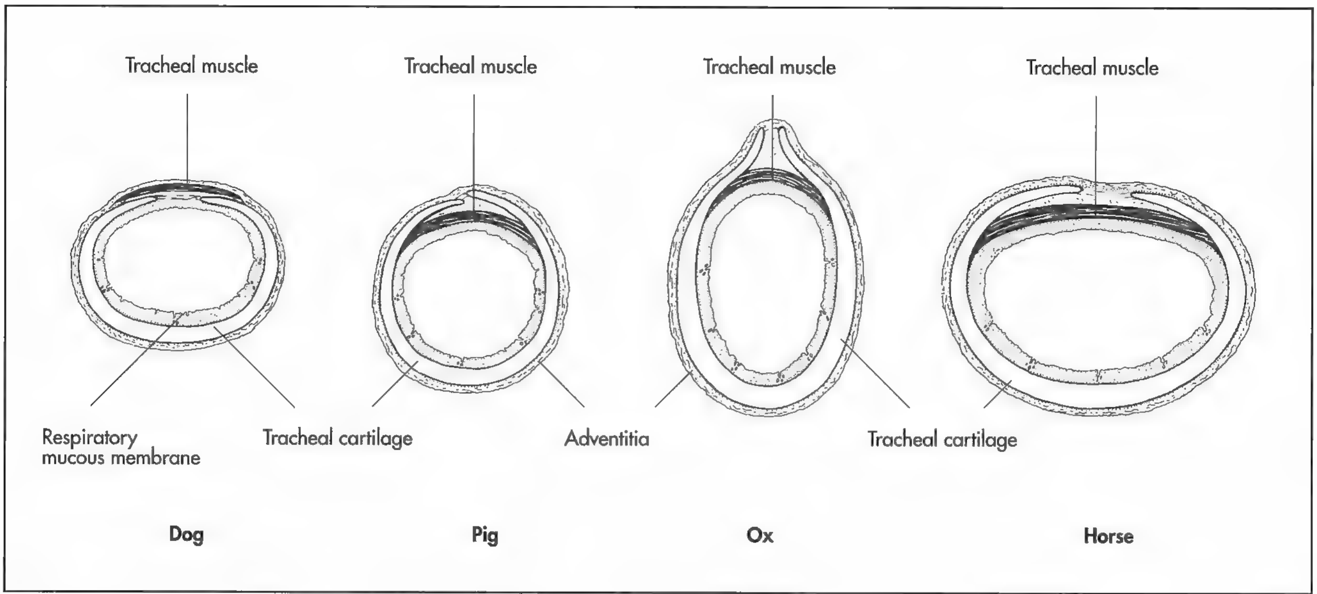

Fig. 8-25. Transverse section of the trachea of the different domestic species, schematic.

Lymph vessels of the larynx drain into the medial retropharyngeal and deep cervical lymph nodes.

Trachea (trachea)

The trachea extends from the cricoid cartilage of the larynx to its bifurcation. It consists of a series of C-shaped hyaline cartilages, connected by ligaments. The number of the tracheal cartilages varies among individuals:

◆ Horse:	48–60
◆ Ox	48–60
◆ Sheep:	48–60
◆ Goat:	48–60
◆ Pig:	29–36
◆ Dog:	42–46
◆ Cat:	38–43

The **tracheal cartilages** are open dorsally and have different shapes in the different domestic species (Fig. 8-25). The space left by failure of these cartilages to meet dorsally is bridged by the transverse running **tracheal muscle** and connective tissue. The so-formed rings are united in a longitudinal direction by bands of **fibroelastic tissue.** The trachea is lined by **respiratory mucosa** with a pseudostratified, ciliated epithelium and have mucus secreting glands over its entire length. The outer layer is composed of adventitia in the neck and of serosa in the thorax. The adventitia consists of loose connective tissue, which connects the trachea to adjacent organs. The caudal laryngeal nerves pass within the tracheal adventitia.

The trachea passes from the larynx, through the visceral space of the neck ventral to the cervical spine and the longus colli muscle to the thoracic inlet. It continues to its bifurcation dorsal to the base of the heart at the level of the fifth intercostal space. In ruminants and pigs a separate tracheal bronchus arises proximal to the tracheal bifurcation and aerates the accessory lobe of the right lung present in these species.

The **cervical portion of the trachea** maintains a median position with an altering relationship to the esophagus depending on its location. Ventrally it is related to the long hyoid muscles. The common carotid artery and the vagosympathetic trunk pass on its lateral sides.

Lung (pulmo)

The **right** and the **left lung** are grossly alike and are connected with each other at the bifurcation of the trachea. They are elastic, air-filled organs with a soft, spongy texture. The colour depends on the blood content: it is pale pink to orange in animals which have been exsanguinated, but deep red when filled with blood. The lungs occupy most of the thoracic cavity and each lung is invaginated in the corresponding pleural sac. A thin fluid filled cleft is present between the **viscera pleura (pleura pulmonalis)** and the **parietal pleural,** which functions to reduce friction during respiration. (For a more detailed description of the pleura see chapter 6.)

Each lung has a convex **costal surface** (facies costalis) adjacent to the thoracic wall, a **mediastinal surface** (facies mediastinalis) towards the mediastinum and a **diaphragmatic surface** (facies diaphragmatica), which lies against the surface of the diaphragm.

Dorsally the mediastinal and the costal surface meet in the thick, rounded **dorsal border** (margo dorsalis seu obtusus), which occupies the gutter shaped space between the ribs and the vertebrae. Ventrally they meet in the thin **ventral border** (margo ventralis seu acutus), which is recessed over the heart to form the **cardiac notch** (incisura cardiaca), which allows the pericardium to contact the lateral thoracic wall.

The diaphragmatic surface meets the costal surface in the **basal border** (margo basalis) and the mediastinal surface in the **mediastinal border** (margo mediastinalis). The apex of

Tab. 8-1. Summary of the pulmonary lobes of the different animales (Ellenberger and Baum, 1943).

	Left lung	Right lung
Dog and Cat	Cranial lobe divided Caudal lobe	Cranial lobe Middle lobe Caudal lobe Accessory lobe
Pig	Cranial lobe divided Caudal lobe	Cranial lobe Middle lobe Caudal lobe Accessory lobe
Ox, Goat and Sheep	Cranial lobe divided Caudal lobe	Cranial lobe divided Middle lobe Caudal lobe Accessory lobe
Horse	Cranial lobe Caudal lobe	Cranial lobe Caudal lobe Accessory lobe

the lung extends cranially, together with the pleural cupula, through the thoracic inlet into the visceral part of the neck.

The area of each lung that receives the main bronchus, accompanied by the **pulmonary vessels** (pulmonary artery and vein, bronchial artery and vein, lymph vessels) and **nerves** is known as the **root of the lung** (radix pulmonis).

The lungs are fixed in place by their attachment to the trachea, blood vessels, the mediastinum and the pleura, which detaches the pulmonary ligament dorsomedially to connect the lungs with the mediastinum and the diaphragm.

Structure of the lungs

The lungs are composed of **parenchyma** and **interstitium** (stroma). The pulmonary parenchyma is the organ where oxygen from the atmosphere and carbon dioxide from the blood are exchanged. It comprises the bronchioles and their branches and the terminating pulmonary alveoli. The interstitium consists of elastic and collagenous soft tissue, which includes mixed glands, smooth muscle fibres, nerve fibres, blood and lymph vessels.

The **surfaces of the lungs** are covered by the pulmonary pleura. Beneath the pleura a fibrous capsule encloses the organ and forms septa between the lobules, which are more (ox) or less (horse) distinct depending on the species. The **elasticity** of the interstitial tissue is responsible for the capability of the lung to expand on inspiration and collapse on expiration. Loss of this elasticity, which occurs naturally with ageing, but also in certain pathological conditions, reduces respiratory efficiency. In the horse for example, **chronic obstructive pulmonary disease (COPD)** causes pulmonary emphysema, where the fibres of the interstitium are torn.

Severely affected animals strain on expiration ("heaving"), which has to be assisted by contraction of the abdominal musculature. In advanced cases this leads to the formation of a visible groove between the aponeurosis and the muscular part of the external oblique abdominal muscle.

Bronchial tree (arbor bronchialis)

The bronchi divide within the lungs **dichotomously or trichotoumously** with each new generation being smaller in diameter, thus forming the bronchial tree (Fig. 8-30 and 33). Based on function, the bronchial tree can be divided into two parts:

- **Respiratory passageways:**
  - Principal bronchi (bronchi principales),
  - Lobar bronchi (bronchi lobares),
  - Segmental bronchi (bronchi segmentales),
  - Subsegmental bronchi (bronchi subsegmentales),
  - True and terminal bronchioli (bronchioli veri et bronchioli terminales).
- **Sites of gaseous exchange within the lungs are:**
  - Respiratory bronchioli (bronchioli respiratorii),
  - Alveolar ducts (ductus alveolares),
  - Alveolar sacs (sacculi alveolares) and
  - Pulmonary alveoles (alveoli pulmonis).

The bronchial tree begins with the bifurcation of the trachea by the formation of the **right** and **left principal bronchus** (bronchus principalis dexter et sinister). Each principal bronchus divides into **lobar bronchi** (bronchi lobares), which supply the various lobes of the lungs and are named according to the lobe supplied. Within the lobe, the lobar bronchi divide into **segmental bronchi** (bronchi segmentales).

The segmental bronchi and the lung tissue they ventilate are referred to as **bronchopulmonary segments** (segmenta bronchopulmonalia). These segments are cone-shaped with

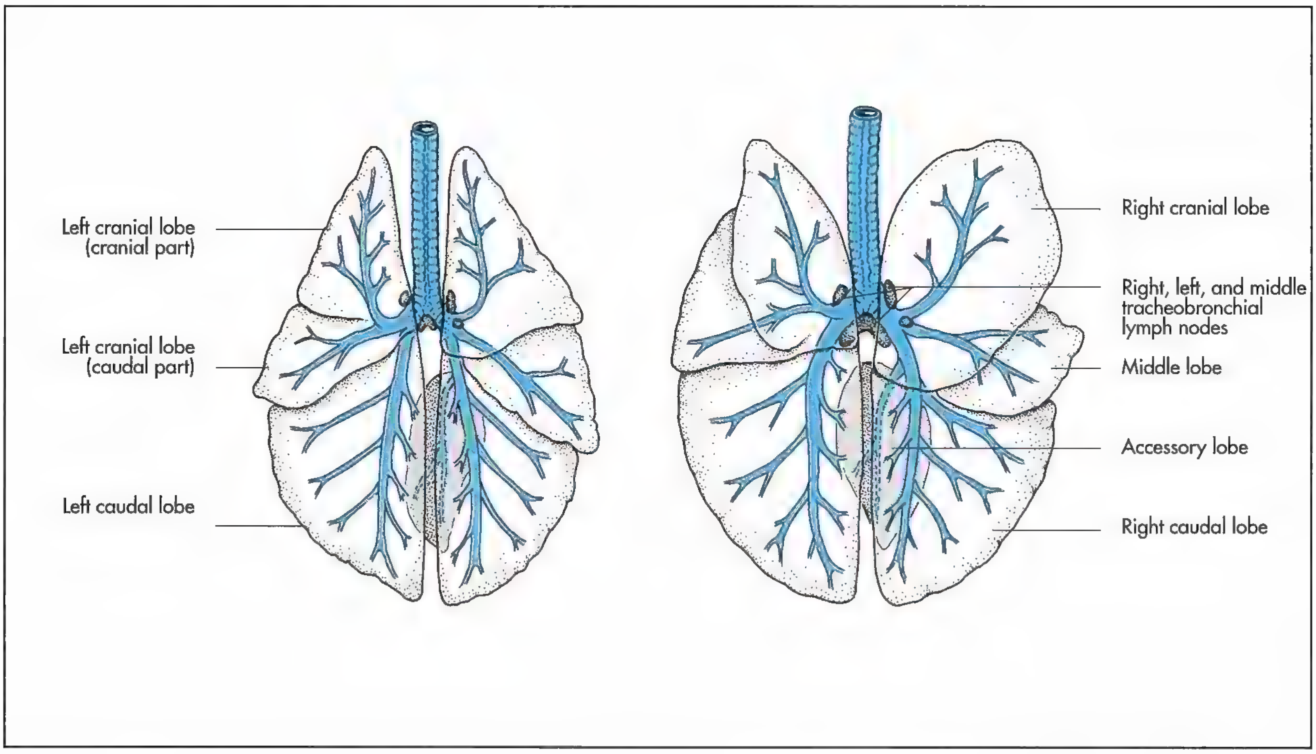

Fig. 8-26. Lung lobes, bronchial tree and lymphnodes of the cat (left) and the dog (right), dorsal aspect, schematic (Ghetie, 1958).

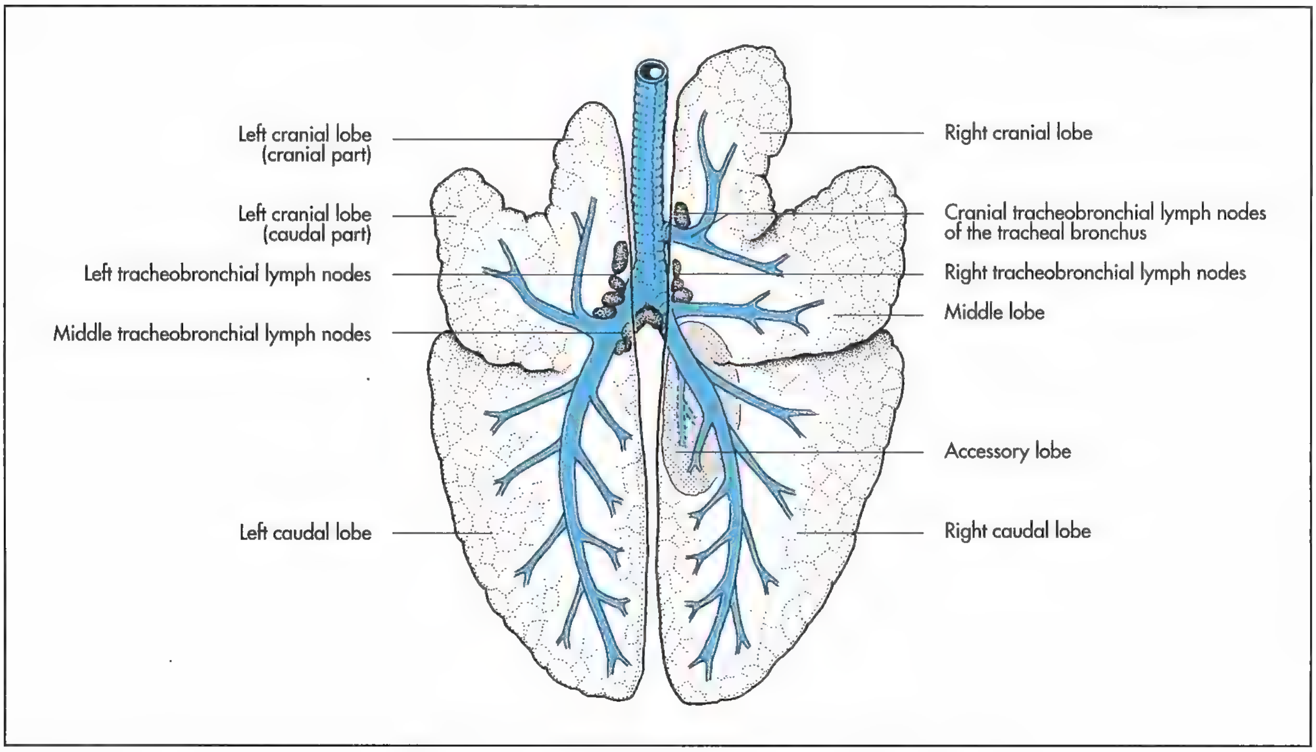

Fig. 8-27. Lung lobes, bronchial tree and lymphnodes of the pig, dorsal aspect, schematic (Ghetie, 1958).

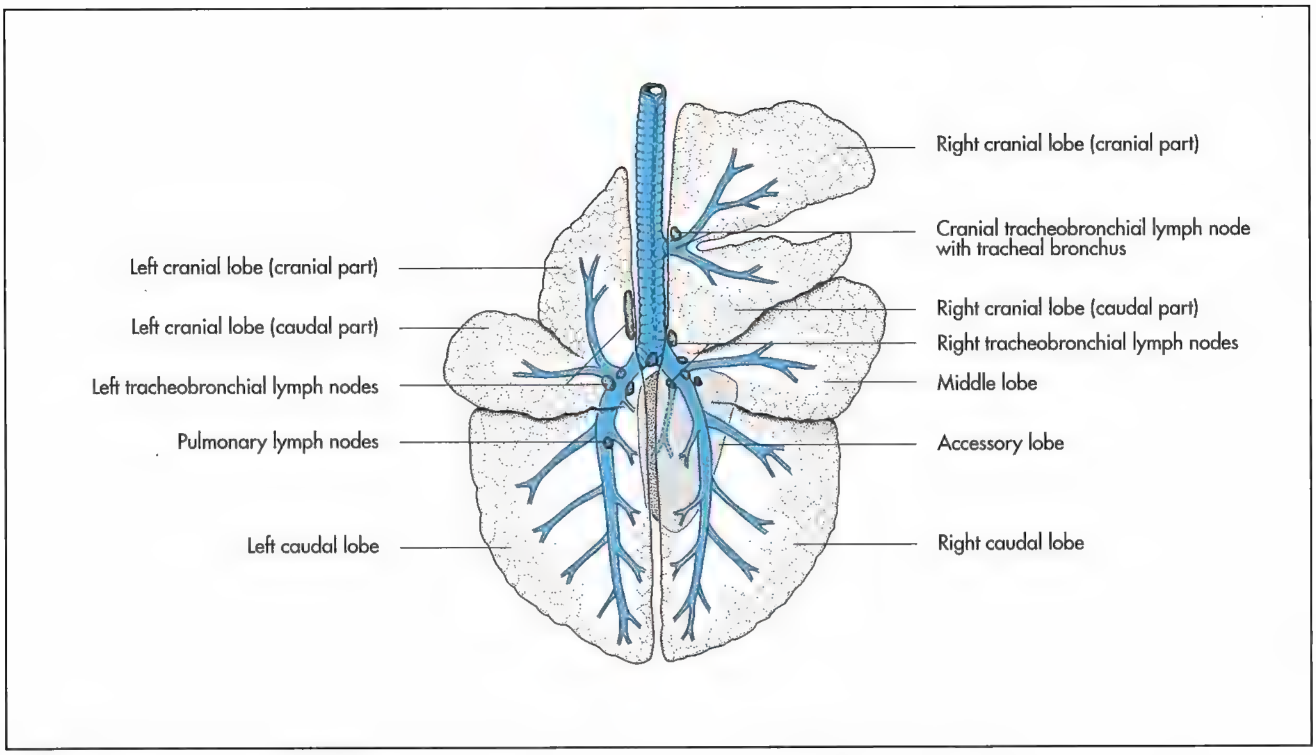

Fig. 8-28. Lung lobes, bronchial tree and lymphnodes of the ox, dorsal aspect, schematic (Ghetie, 1958).

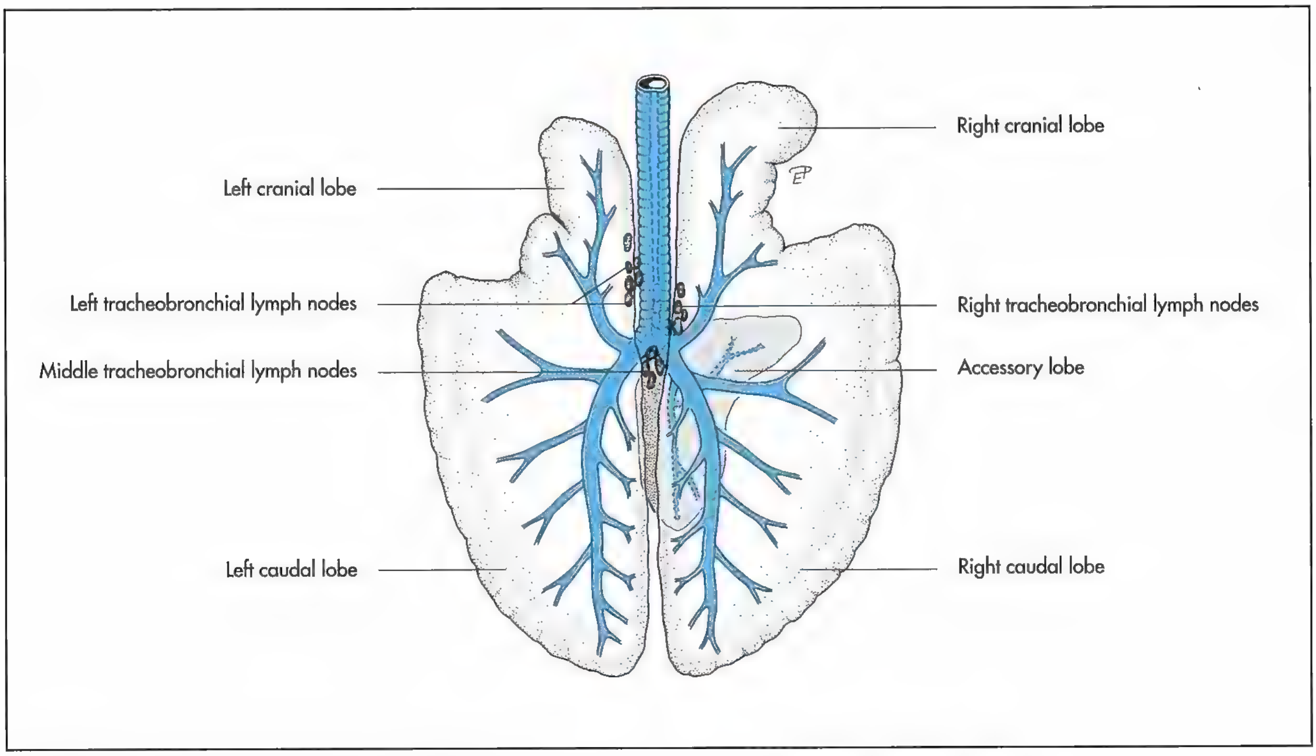

Fig. 8-29. Lung lobes, bronchial tree and lymphnodes of the horse, dorsal aspect, schematic (Ghetie, 1958).

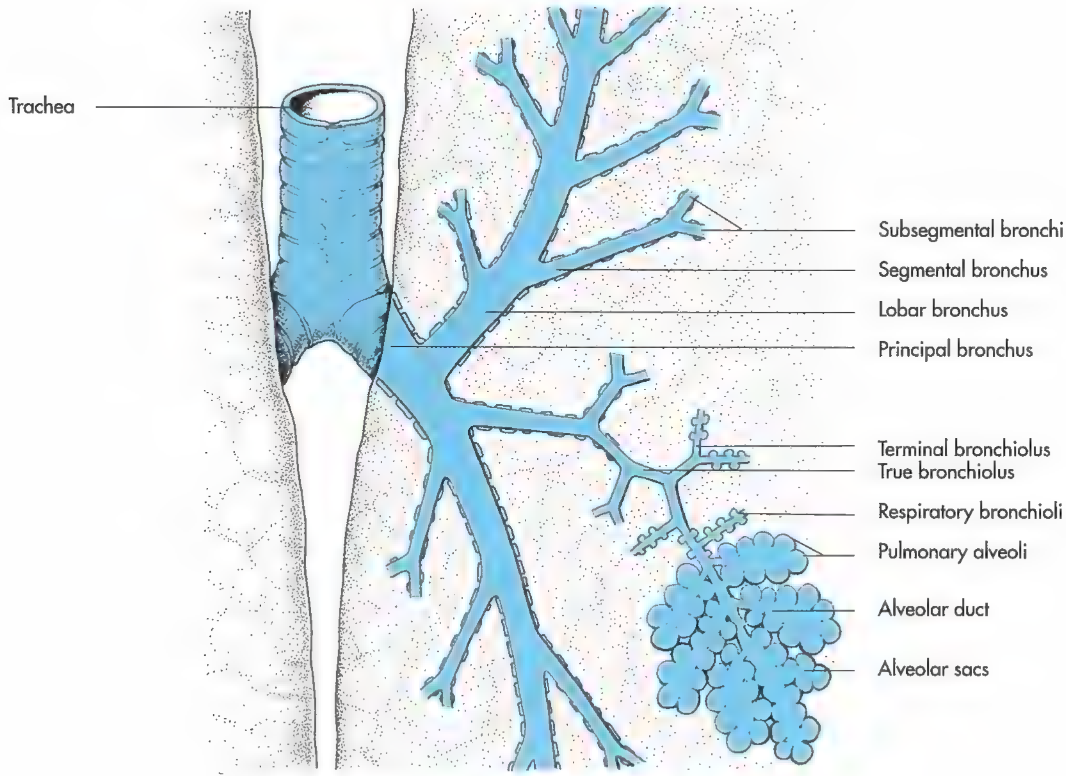

Abb. 8-30. Bronchial tree, schematic.

the apex of the cone pointing towards the pulmonary root and the base being located near the free surface of the lung. The **interior of all bronchi** is lined by **respiratory mucosa,** the wall contains mixed glands, smooth muscle fibres and hyaline cartilage (Fig. 8-34). In contrast to the segmental bronchi the walls of the following bronchioli do **not contain glands** and are **not supported by hyaline cartilagenous** elements, but still have muscular fibres and are also lined by respiratory mucosa. The last generation without pulmonary alveolar cells in their wall segments are the **true bronchioli** (bronchioli veri), which branch to form the **terminal bronchioli.**

These divide into **respiratory bronchioli,** which contain a few pulmonary alveolar cells in their walls. The respiratory bronchioli divide into secondary and tertiary respiratory bronchioles before they are followed by the alveolar ducts, which are completely surrounded by alveoli. The **alveolar ducts** terminate in the **alveolar sacs** (Fig. 8-35). The respiratory bronchioli, the alveolar ducts, their sacs and the pulmonary alveoli provide the **air-blood interface** through which the **gaseous exchange takes place.** During branching the respiratory epithelium becomes thinner and is finally replaced by a single layer of alveolar squamous cells. The **pulmonary alveoli** are lined by a single layer of **pneumocytes (type I and II),** with an underlying basal membrane and are surrounded by a dense capillary network. The alveoli and the surrounding capillaries form the **blood-air barrier.** (For a more detailed description of the microscopic structure of the lung see histology textbooks.)

Lobes of the lung (lobi pulmonis)

The lobes of the lung are properly defined by the ramification of the bronchial tree. Each lobar **bronchus** supplies its **own lobe,** which is named accordingly: e.g. cranial bronchus – cranial lobe, accessory bronchus – accessory lobe.

According to this system the left lung is divided into a **cranial** (lobus cranialis) and a **caudal lobe** (lobus caudalis). In addition to cranial and caudal lobes the right lung possesses a **middle** (lobus medius) and an **accessory lobe** (lobus accessorius). In some species the cranial lobes are further subdivided into cranial and caudal parts. The lobation of the lungs of the different domestic mammals is listed in Table 8-1 and shown in Fig. 8-26 to 29.

The **accessory lobe** occupies the **mediastinal recess** (recessus mediastini), which is located between the mediastinum, the caudal vena cava and its mesentery (plica venae cavae) to the right, the pericardium cranially and the diaphragm caudally. In the dog and the cat, part of the accessory lobe is outside the mediastinal recess. In ruminants and pigs the right cranial lobe is ventilated by the **tracheal bronchus,** which

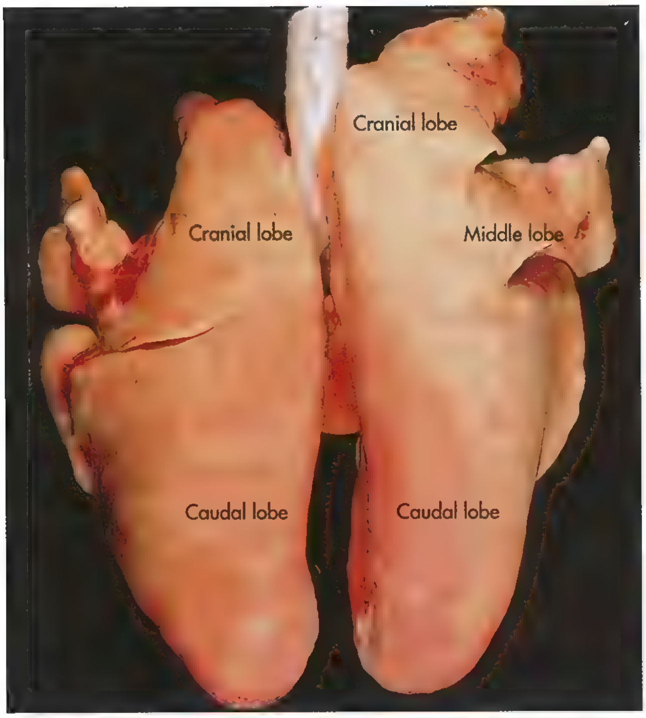

Fig. 8-31. Lungs of a pig, dorsal aspect (courtesy of PD Dr. J. Maierl, Munich).

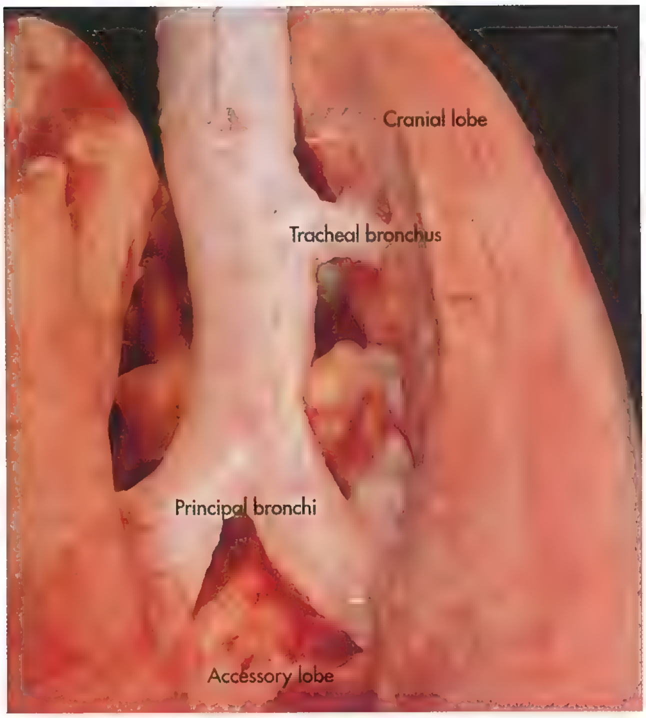

Fig. 8-32. Lungs of a pig, demonstrating the tracheal bronchus, dorsal aspect (courtesy of PD Dr. J. Maierl, Munich).

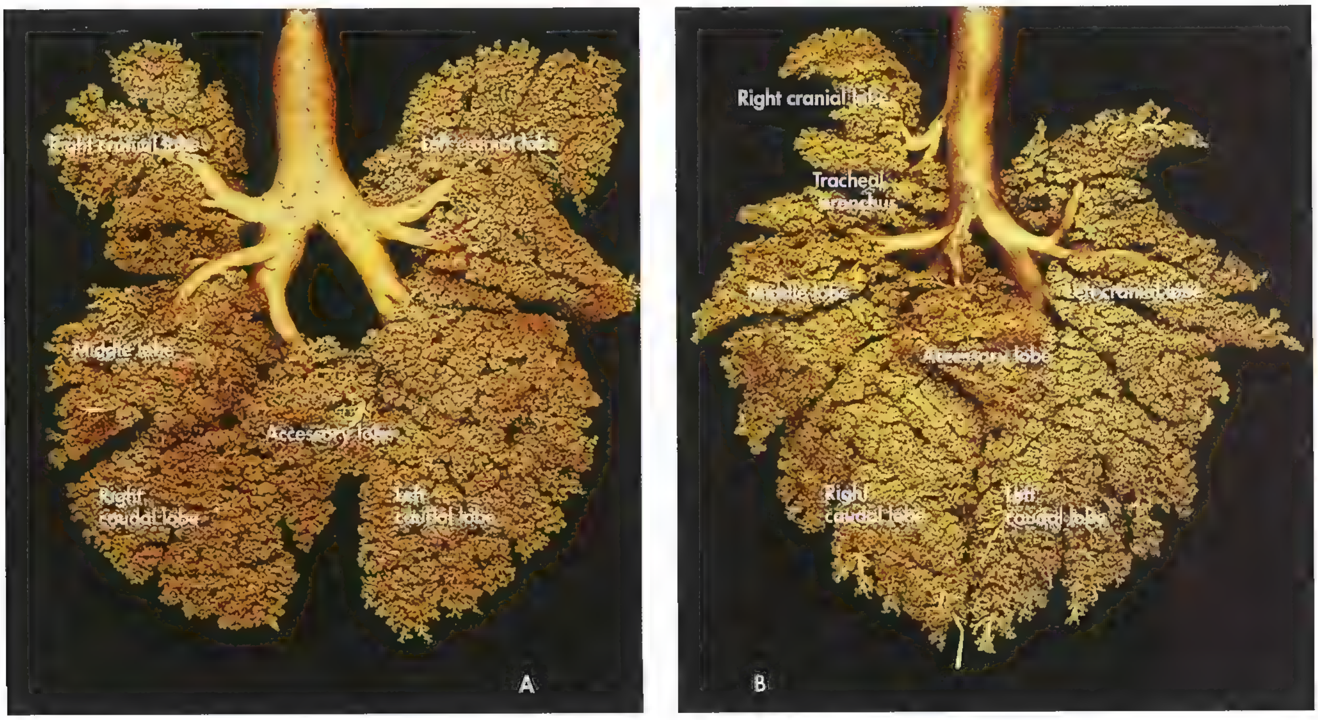

Fig. 8-33. Trachea and bronchial tree of a dog **(A)** and the pig **(B)**, corrosion cast, ventral aspect.

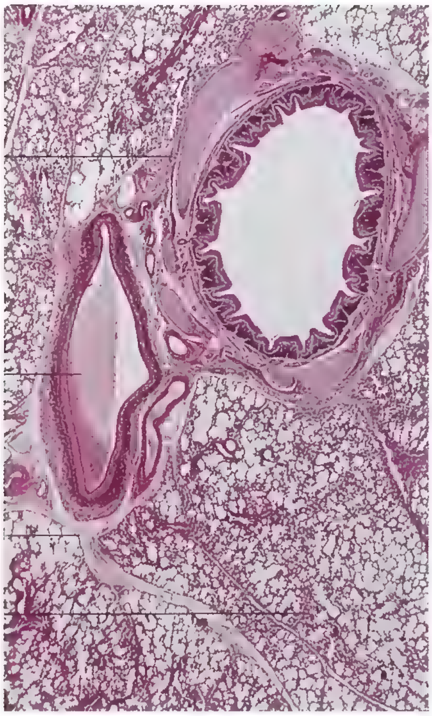

Fig. 8-34. Histologic section of the lung demonstrating brochus, vein, parenchyma and interstitium.

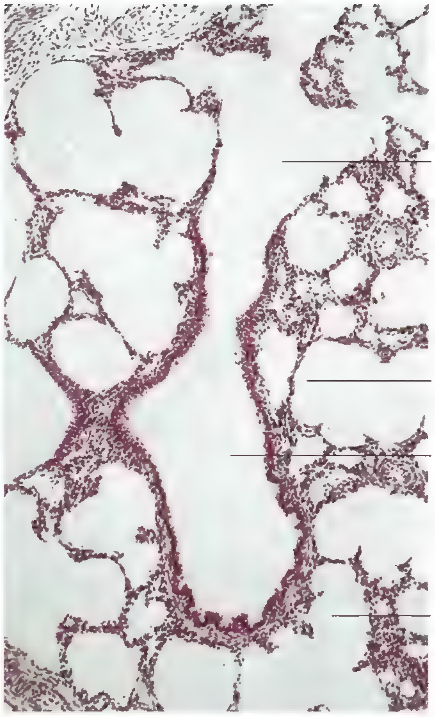

Fig. 8-35. Histologic section of the lung demonstrating pulmonary alveoli.

arises independently from the trachea cranial to its bifurcation (Fig. 8-27, 28, 32 and 33B).

The identification of the lungs of individual species is most conveniently based on the degree of lobation and lobulation. The lungs of ruminants and pigs are conspicuously lobated and lobulated. The lungs of the horse shows almost no lobation and very faint lobulation externally. Those of carnivores are very deeply fissured into lobes, but show little external evidence of lobulation.

Blood vessels

The pulmonary arteries carry non-aerated blood from the right ventricle of the heart to the lungs for gaseous exchange. The pulmonary veins return aerated blood from the left atrium to the heart.

An additional nutritional blood supply is provided by the bronchoesophageal artery and vein. The pulmonary trunk and its branches, the pulmonary arteries, are the only arteries in the body, which carry venous blood. Their branches follow the bronchial tree into the organ until they reach the pulmonary alveoli, around which they form a dense capillary network. Each alveolus is surrounded by about 10 capillary loops. Part of these capillaries are permanently perfused, while others are only perfused when oxygen demand increases.

The branches of the pulmonary veins do not always follow the bronchial tree, but sometimes run separately.

Lymph nodes

The lymph from the lungs is drained to the tracheobronchial lymph nodes, which are situated around the tracheal bifurcation (Fig. 8-26 to 29). According to their location they can be grouped into **left, right** and **middle tracheobronchial lymphnodes.** In species with a tracheal bronchus there are also cranial tracheobronchial lymph nodes. The ox has **additional pulmonary lymph nodes** situated along the main bronchi.

From these locations lymph is drained via the mediastinal lymphnodes into the thoracic duct.

Innervation

The lung receives **parasympathetic** and **sympathetic nerves** from a pulmonary plexus within the mediastinum. Sympathetic fibres from the medial and **caudal cervical ganglion** radiate into the mediastinum where they unite with parasympathetic fibres from the vagus to form the **cardiac plexus** at the base of the heart, which delivers the nerve fibres for the pulmonary plexus. Efferent fibres supply the bronchial glands and muscles and the blood vessels, afferent fibres come from the mucosa and stretch receptors.

Clinical terms related to the respiratory system:
Rhinits, sinusitis, laryngitis, laryngoscopy, laryngotomy, tracheotomy, bronchitis, bronchoscopy, bronchography, pneumonia, pleuritis etc.

9 Urinary system (organa urinaria)

H. E. König, J. Maierl and H.-G. Liebich

The organs of the urinary system are closely related to the reproductive organs in terms of embryonic development and anatomic topography. In addition, they share common terminal segments, located in the pelvic cavity. Therefore the two systems are often described under one heading, the **urogenital system** (apparatus urogenitalis).

The organs of the **urinary system** (organa urinaria) include the **kidneys** (renes), **ureters, bladder** (vesica urinaria) and **urethra.** The paired kidneys produce urine from the circulatory system by filtration, secretion, reabsorption and concentration. The ureters convey the urine from the kidneys to the bladder, where it is stored until it is discharged through the urethra.

Kidney (nephros, ren)

The main function of the kidney is to maintain the composition of the body fluids within the physiological range. It removes endproducts of the metabolism and excrete substances from the blood. This is achieved by filtering plasma, initially extracting a large volume of fluid, the ultrafiltrate, which is also

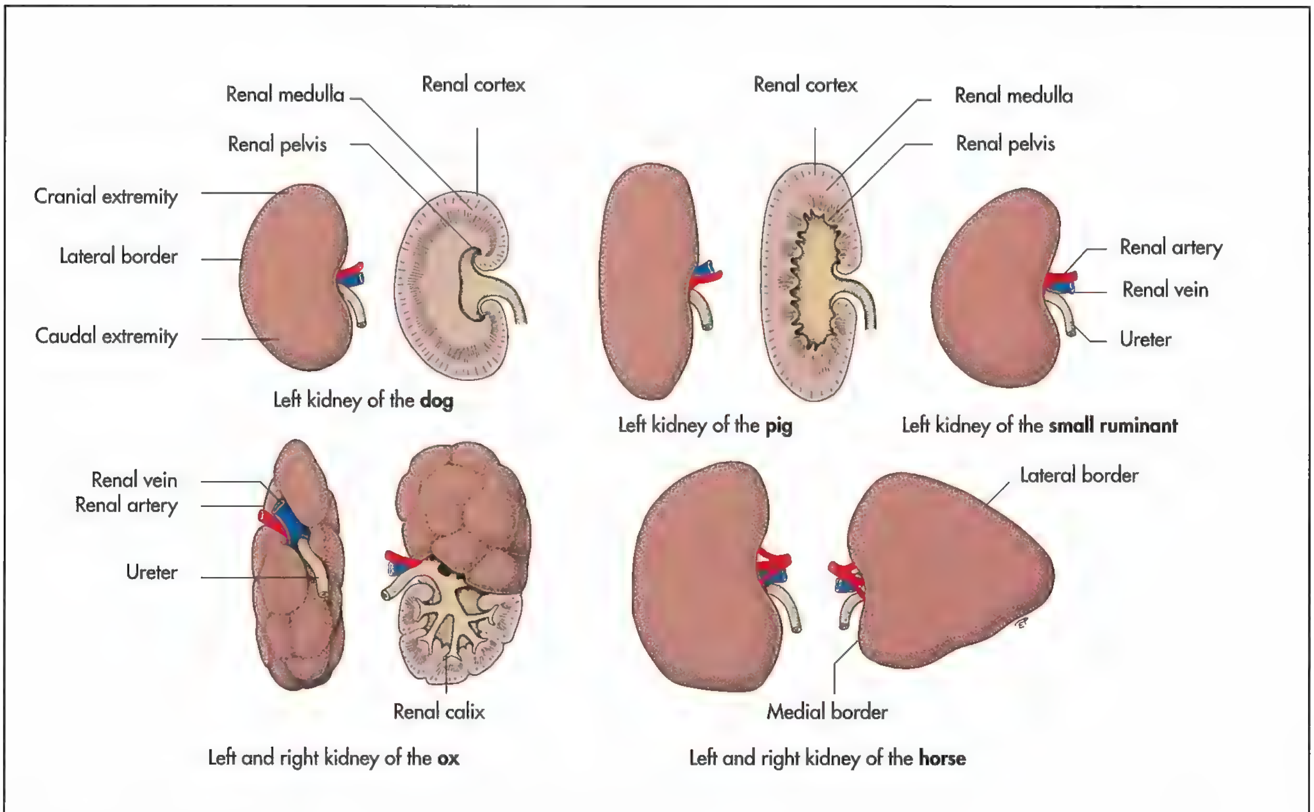

Fig. 9-1. Kidneys of the domestic mammals with renal pelvis, ureter and renal artery and vein, schematic.

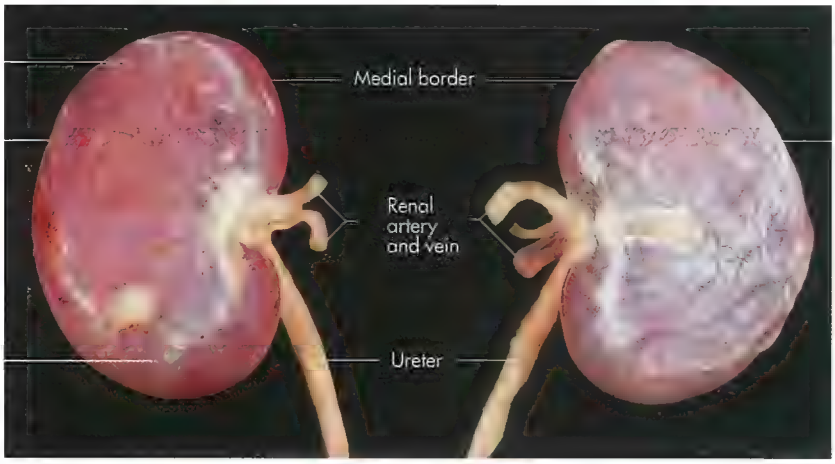

Fig. 9-2. Left and right kidneys of a dog with renal capsule, dorsal aspect.

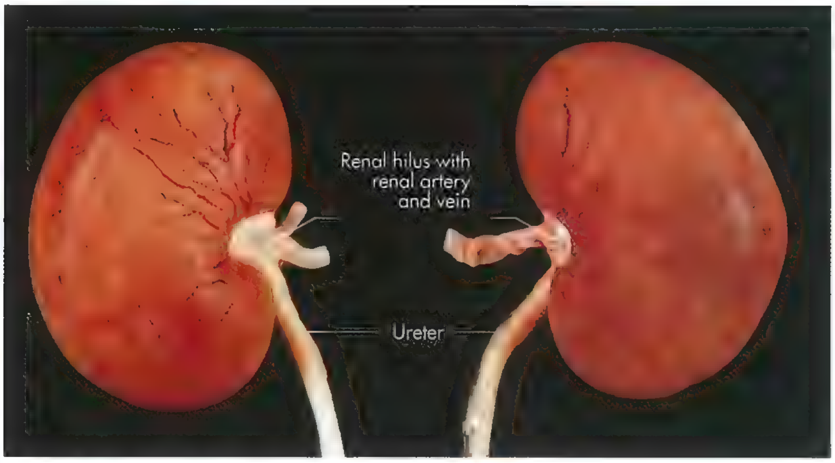

Fig. 9-3. Left and right kidneys of a dog, renal capsule removed, dorsal aspect.

Fig. 9-4. Equatorial section of the unilobar kidney of a dog.

called **primary urine.** The **ultrafiltrate** is iso-osmotic and iso-tonic and essentially contains the same substances as plasma with the exception of the high molecular weight protein molecules. The ultrafiltrate is subjected to further processing by which useful substances (e.g. water, glucose, electrolytes and amino acids) are selectively reabsorbed and waste substances concentrated for elimination. The end product of these processes is the **secondary urine,** which has only 1–2% of the volume of the primary urine. In large dogs 1000 to 2000 litres of blood perfuse the kidneys daily from which 200 to 300 litres are filtered as the primary urine, which is then reduced by reabsorption processes to the 1–2 litres, which are eliminated.

The kidneys also have **endocrine functions.** They produce the hormone renin, which converts the plasma protein angiotensinogen into angiotensin I. In the liver the angiotensin converting enzyme converts angiotensin I into angiotensin II, which causes arterial constriction, thus increasing the blood pressure. Bradykinin is another hormone produced by the kidneys, which causes dilatation of blood vessels. Erythropoetin, also produced by the kidneys, enhances erythropoesis.

Location of the kidneys

The kidneys are paired structures lying retroperitoneally pressed against the dorsal abdominal wall on either side of the vertebral column. They are predominantly located in the lumbar region, but extend cranially under the last ribs into the intrathoracic part of the abdomen Their position changes by half the length of a vertebra, with the movement of the diaphragm.

In domestic mammals, other than the pig, the **right kidney** is located further cranial than the left and its cranial extremity lies in contact with the caudate process of the liver and the right hepatic lobe. It lies in a **fossa of the liver** (impressio renalis), which helps to limit its movement. The **left kidney** is more mobile, as an equivalent impression is not present in the liver. In ruminants, the considerable size of the rumen pushes the left kidney towards the right half of the abdomen, where it is suspended by the long and mobile mesonephros caudal to the right kidney. Each kidney is embedded in fat, which protects against distorting pressure from the adjacent organs.

Shape of the kidneys

The kidneys are reddish-brown organs, the shape of which varies considerably among the domestic mammals (Fig. 9-1 to 4). The basic form is **bean-shaped** as found in the dog, cat, sheep and goat. The kidneys of the pig are more flattened, the right kidney of the horse has a **valentine heart shape,** while the left has a bean to **pyramidal shape.** The bovine kidney has an **irregular oval shape** and its surface is fissured to divide the organ into many lobes. The kidneys of the other domestic mammals have a smooth surface. A complete separation of the different renal lobes is found in certain marine species, whose kidneys resemble a bunch of grapes.

The kidney can be described in terms of its dorsal and ventral surfaces, lateral and medial borders and cranial and caudal extremities or poles. The medial border of the kidney is indented to form the **renal hilus** (hilus renalis), through which the dilated origin of the ureter, the **renal pelvis** (pelvis renalis) exits and the renal vessels and nerves (Fig. 9-1 to 4) enter the kidney.

Structure of the kidney

The renal parenchyma is enclosed within a tough **fibrous capsule,** which passes inward at the medial aspect of the kidney to line the walls of the renal sinus. This capsule can be easily removed from a healthy kidney during post-mortem examination, but adheres after the tissue is scarred by disease.

The parenchyma of the kidney is visibly (Fig. 9-10 and 15) divided into:

- **Renal cortex** (cortex renis),
  - Peripheral zone (zona peripherica),
  - Juxtamedullar zone (zona juxtamedullaris),
- **Renal medulla** (medulla renis),
  - External zone and
  - Internal zone.

The **renal cortex** is reddish-brown in colour and has a finely granular appearance. The cortex is delineated into **cortical lobules** (lobuli corticales), by radial lines, which identify the path of the **radiate arteries** (aa. radiatae).

The **renal medulla** consists of a dark **outer zone** and a **paler inner zone,** which is radially striated and extends to the **renal sinus** (Fig. 9-7 and 9).

During embryonic development, all mammalians pass through a stage, where the kidneys have a multilobular structure, although in most species the number of lobes is considerably reduced by fusion of the separate lobes. The degree of fusion varies among species.

In the ox and the pig, the medulla and its associated cortex are divided into **pyramidal shaped lobes.** The apex of each lobe is directed towards the renal sinus and forms a papilla, which fits into a **cup-like expansion** (calix) of the renal sinus or ureter. Kidneys that retain this architecture are referred to as **multilobar** or **multipyramidal.** While the kidney of the pig has a smooth surface, in the ox the multilobar organisation of the kidney is revealed by the fissures that penetrate the organ between the different lobes from the surface.

In the dog, horse and sheep all the lobes fuse finally to form a single medullary mass with a continuous cortical shell surrounding it. The fusion joins the papillae in a common **renal crest** (crista renalis) (Fig. 9-2 to 4). Even in this **unilobar type** of kidney some evidence of its complex origin is retained: in the dog and cat pseudopapillae project dorsal and ventral to the papillary crest, separated by recesses of the **renal pelvis** (recessus pelvis) (Fig. 9-19). These recesses are divided into two parts by the interlobar arteries and veins. The following types of kidney can be distinguished based on the degree of fusion:

- **Unilobar kidneys** with a smooth surface and a single renal papilla: Cat, dog, horse, small ruminants.
- **Multilobar kidneys** with a smooth surface and multiple papillae: Pig.
- **Multilobar kidneys** with a lobated surface and multiple papillae: Ox.

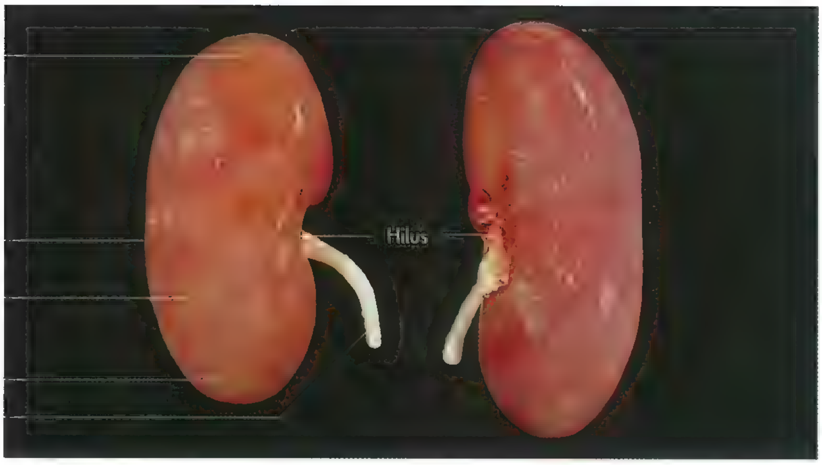

Fig. 9-5. Left and right kidney of a pig, ventral aspect.

Fig. 9-6. Kidney of a pig, demonstrating a smooth surface and an internal multilobar structure.

Fig. 9-7. Paramedian section of the unilobar kidney of a dog.

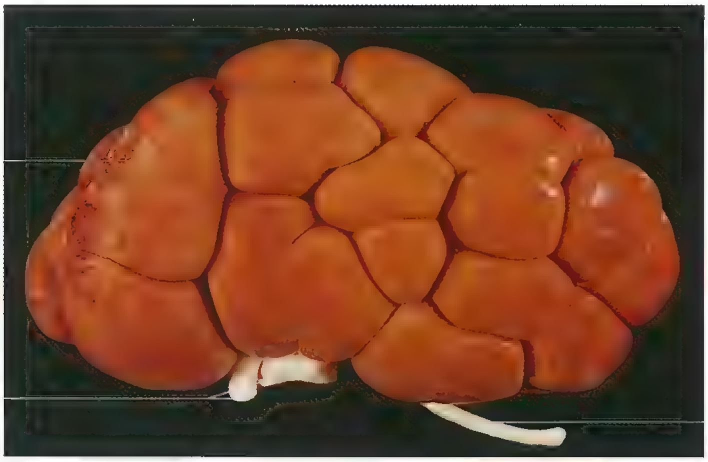

Fig. 9-8. Multilobar kidney of an ox.

Fig. 9-9. Section of the multilobar kidney of an ox.

Functional unit of the kidney

The functional units of the kidney are the **nephrons** or **renal tubules.** The nephrons are responsible for urine production, while the subsequent collecting tubules convey the urine to the renal pelvis. They form a system of continuous convoluted tubules within the kidney, the number of which varies among the different domestic mammals. There are up to 400 000 nephrons in the kidney of a dog, 500 000 in the cat, 1 Million in the pig, 4 Million in the ox and up to 2.7 Million nephrons in the kidney of a horse.

The renal tubules are supported by a connective tissue interstitium, through which blood vessels and nerves pass.

Each nephron is composed of several segments, which have the same embryological origin from the meta nephron tissue:

- Glomerular capsule (capsula glomeruli),
- Proximal convoluted tubule (tubulus contortus proximalis),
- Loop of Henle (ansa nephroni),
  - Descending limb (tubulus rectus proximalis),
  - U-turn (tubulus attenuatus),
  - Ascending limb (tubulus rectus distalis) and
- Distal convoluted tubule (tubulus contortus distalis).

Each nephron begins proximally with a blind-expansion, the double-layered **glomerular capsule** (capsula glomeruli, Bowman-capsule), that is invaginated by a spherical plexus of blood capillaries, the **glomerulus** (Fig. 9-10 and 15). The parietal layer of cells forms the outer wall of the glomerular capsule; the visceral layer the inner wall towards the blood capillaries of the glomerulus. The inner wall is composed of

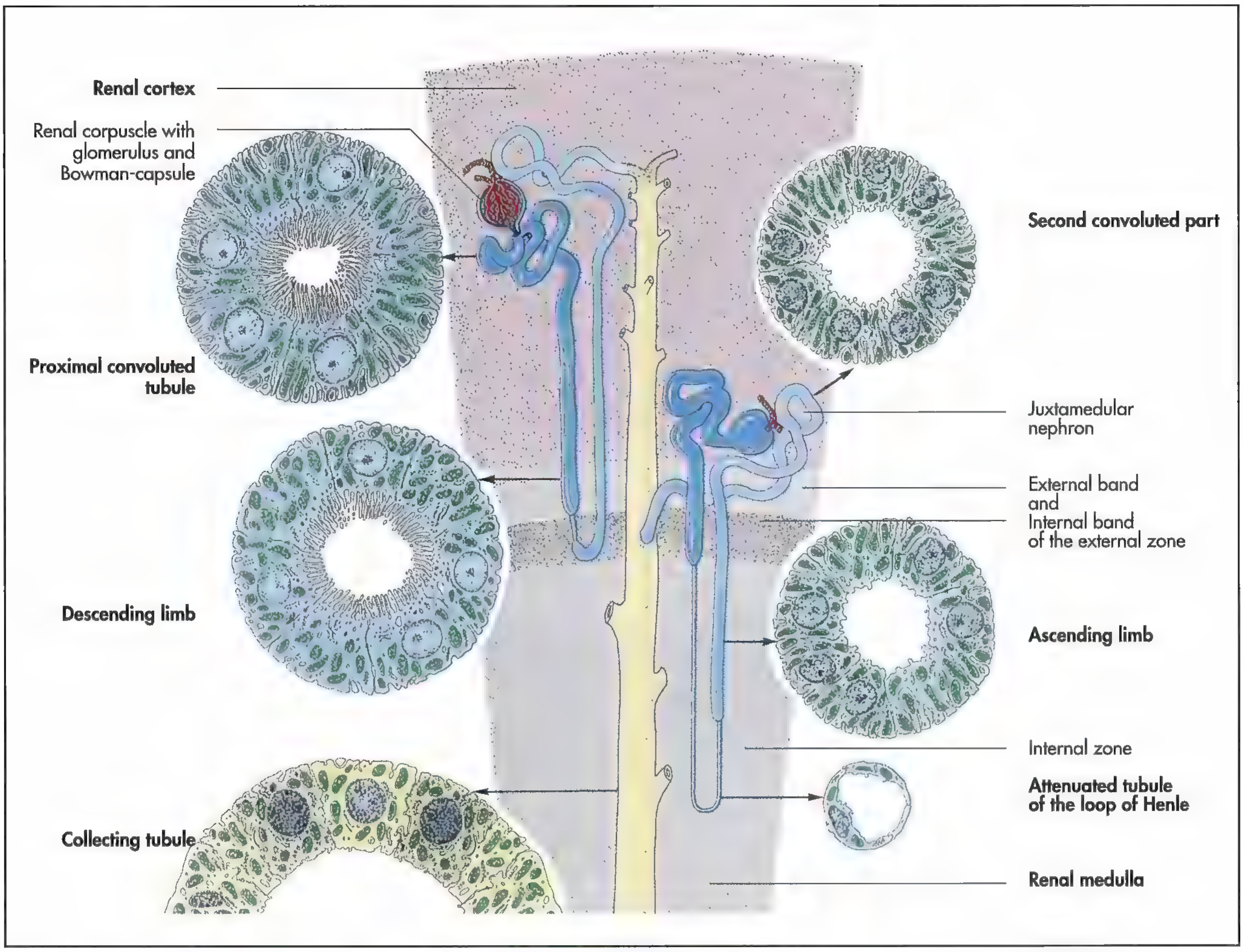

Fig. 9-10. Structure of the functional untis of the kidney, schematic (Liebich, 2004).

a single layer of flat **podocytes,** which form, together with the endothelium of the capillary wall and the semi-permeable basilar membrane, the **blood-urine barrier.** The space between the parietal and visceral wall of the glomerular capsule receives the **primary urine** or **ultrafiltrate.**

The **glomerulus** consists of 30–50 delicate capillary loops, which are formed by the **small afferent artery** (arteriola glomerularis afferens). The glomerulus and the glomerular capsule constitute the **renal corpuscle** (corpusculum renis), sometimes spoken of as a **Malpighian corpuscle,** which is just large enough (100–300 µm) to be visible to the unaided eye. Renal corpuscles are scattered throughout the cortex and give it a finely granulated appearance. No renal corpuscles are present in the medulla.

The remaining part of each nephron consists of a continuous tube, which can be divided into several successive segments. It starts with the coiled and twisted **proximal convoluted tubule** (tubulus contortus proximalis), which is located close to the glomerular capsule from which it arises (Fig. 9-10 and 15). This segment gradually straightens toward the medullary portion of the kidney as the **descending limb** (tubulus rectus proximalis) of the **loop of Henle** (ansa nephroni). The loop of Henle resembles a long **hairpin loop** with three segments: The **descending limb** (tubulus rectus proximalis) is relatively narrow and runs through the medulla to approach the papilla before making a **U-turn** (tubulus attenuatus) (Fig. 9-10 and 15). The following **ascending limb** (tubulus rectus distalis) runs peripherally again into the cortex increasing in diameter. It forms a **second convoluted part** (tubulus contortus distalis), that is also located close to the renal corpuscle of origin.

A short junctional segment joins the distal convoluted tubule to a **straight collecting tubule** within a medullary ray. One collecting tubule serves many nephrons before it unites with other **collecting tubules** to form a **papillary duct** (ductus papillaris), close to the apex of a renal lobe. Several papillary ducts discharge into the renal pelvis at the **cribriform areas** (area cribrosa), which are confined to the apices of independent papillae (ox and pig) or to specific regions of a common crest (cat, dog, small ruminants, horse) (Fig. 9-15 and 22). (A more detailed description of the macroscopic anatomy of the kidney can be found in standard histology textbooks.)

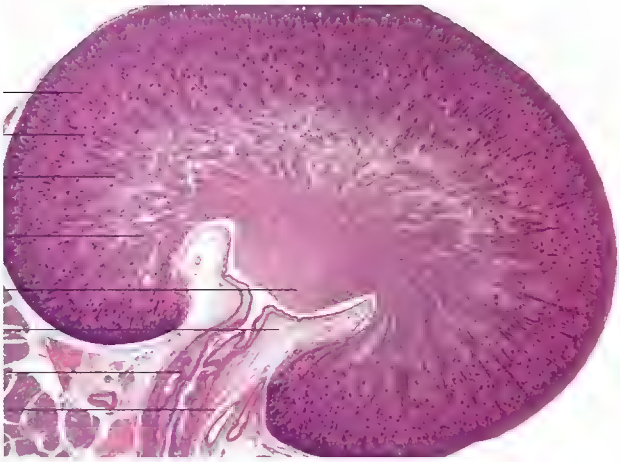

Fig. 9-11. Histological section of the kidney of a dog (Liebich, 2004).

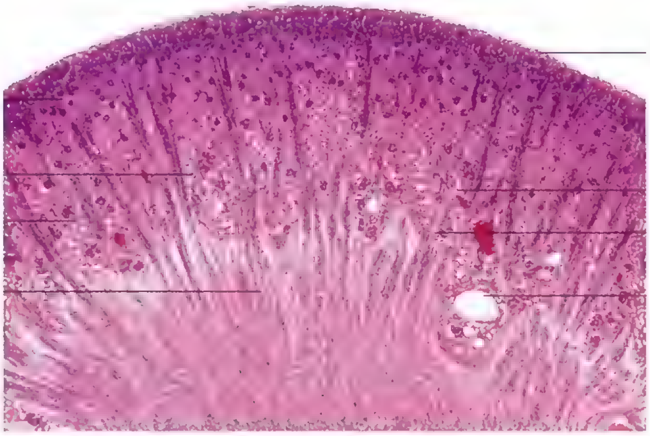

Fig. 9-12. Histological section of the renal cortex and medulla of a dog (Liebich, 2004).

Blood supply

More than 20% of the arterial blood, which is pumped from the left ventricle into the arteries pass through the kidneys. There is significant variation in the exact vascular architecture between the different species and a detailed description can be found in specialised literature. In order to understand the functional mechanisms of the kidney knowledge of the basic principle of renal vascularisation is necessary.

Each kidney is supplied by a **renal artery** (a. renalis), a branch of the abdominal aorta (Fig. 9-2 to 4). The renal artery divides into **several interlobar arteries** at the hilus of the kidney. These follow the divisions between the different renal lobes to the **corticomedullary junction** (Fig. 9-13, 14 and 15), where they branch into **arcuate arteries** (aa. arcuatae). The arcuate arteries curve over the bases of the **medullary pyramids** and give rise to the **interlobular arteries** (aa. interlobulares), which radiate into the cortex to supply the lobules (Fig. 9-14, 15 and 17). Afferent arterioles leave the interlobular arteries to enter the renal corpuscles where it forms the **capillary loops of the glomerulus.**

Following the blood stream the blood vessels of the kidney can be divided into the following principal pattern:

- **Abdominal aorta** (aorta abdominalis):
  - **Renal artery** (a. renalis),
    - Interlobar artery (a. interlobaris),
    - Arcuate artery (a. arcuata),
    - Interlobular artery (a. interlobularis),
      - Afferent glomerular artery (arteriola glomerularis afferens),
      - **Glomerulus,**
      - Efferent glomerular artery (arteriola glomerularis efferens),
      - Capsular branch (ramus capsularis),
      - Capillary plexus around the renal tubules,
    - Interlobular vein (v. interlobularis),
    - Arcuate vein (v. arcuata),
    - Interlobar vein (v. interlobaris),
  - **Renal vein** (v. renalis) and
- **Caudal vena cava** (v. cava caudalis).

Fig. 9-13. Superficial blood vessels of the left kidney of a cat, corrosion cast.

Fig. 9-14. Deep blood vessels of the left kidney of a cat, corrosion cast.

These loops rejoin to form the **efferent arteriole,** which leaves the distal pole of the renal corpuscle to supply a **second capillary plexus** around the tubular segments of the nephrons. This second capillary system drains the blood from the renal cortex into the **interlobular veins,** the **arcuate veins** and the **interlobar veins** (Fig. 9-14, 15 and 17), which finally lead through the **renal veins** to the **caudal vena cava.**

The interlobular arteries also give rise to capsular branches (rami capsulares), which extend to the fibrous capsule of the kidney and into the surrounding fat. Venous drainage of the fibrous capsule is brought about by the **stellate veins** (venulae stellatae) (Fig. 9-16). These connect with veins of the adipose capsule and empty into the interlobular veins.

The kidneys of the cat are given a distinctive appearance by a separate venous system for the renal capsule (Fig. 9-13). These veins do not communicate with the other renal veins, but consist of 3–5 capsular veins, which run on the surface of the kidney in shallow grooves to join the renal vein at the hilus.

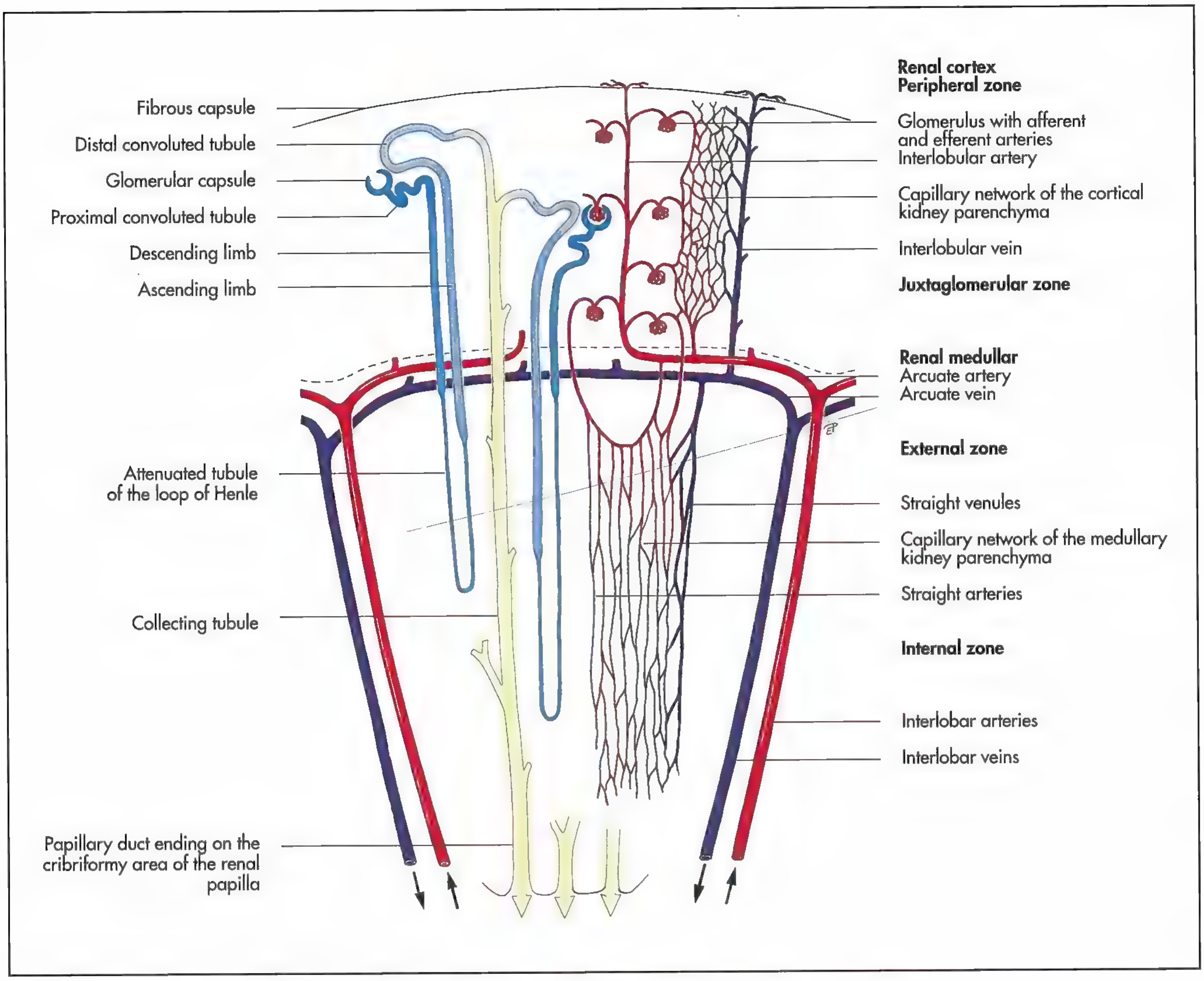

Fig. 9-15. Vascularisation of the kidney, schematic.

From the efferent arterioles of corpuscles, near to the corticomedullary junction, small arteries radiate straight into the medulla (arteriolae rectae). The blood drains from the capillaries into **straight venules** (venulae rectae) and then into the arcuate veins (Fig. 9-15). While the glomeruli are located within the glomerular capsule in the renal cortex, the straight blood vessels are located in the medulla.

The **renal corpuscles** are responsible for the production of the primary urine or ultrafiltrate, while the tubular part of the nephron and the straight blood vessels are responsible for the reabsorption of water and dissolved components from the primary urine.

Lymphatics

The lymphatics are satellites to the blood vessels and terminate in the **lumbar lymph nodes** (lymphonodi lumbales aortici). The lymph nodes of this series located closest to the kidneys are the **renal lymph nodes** (lymphonodi renales).

Innervation

The kidneys receive **sympathetic** and **parasympathetic** fibres from the **solar plexus,** which reach the organ along the renal arteries. Sympathetic fibres form synapses in the **celiac ganglion** (ganglion celiacum), in the **cranial mesenteric ganglion** (ganglion mesentericum craniale), and in smaller ganglia of the **renal plexus.** The dorsal branch vagus contributes the parasympathetic fibres.

Renal pelvis (pelvis renalis)

In the domestic mammals other than the ox, the proximal ureter begins with a common expansion, the **renal pelvis,** into which all the **papillary ducts** open (Fig. 9-22). The renal pelvis is located within the **renal sinus,** but is fused with the renal tissue around the papillae only. In the dog and cat the renal pelvis can be assessed radiographically in contrast studies. In these species the renal pelvis is moulded around the renal crest and extends ventrally and dorsally to form the pelvic recesses,

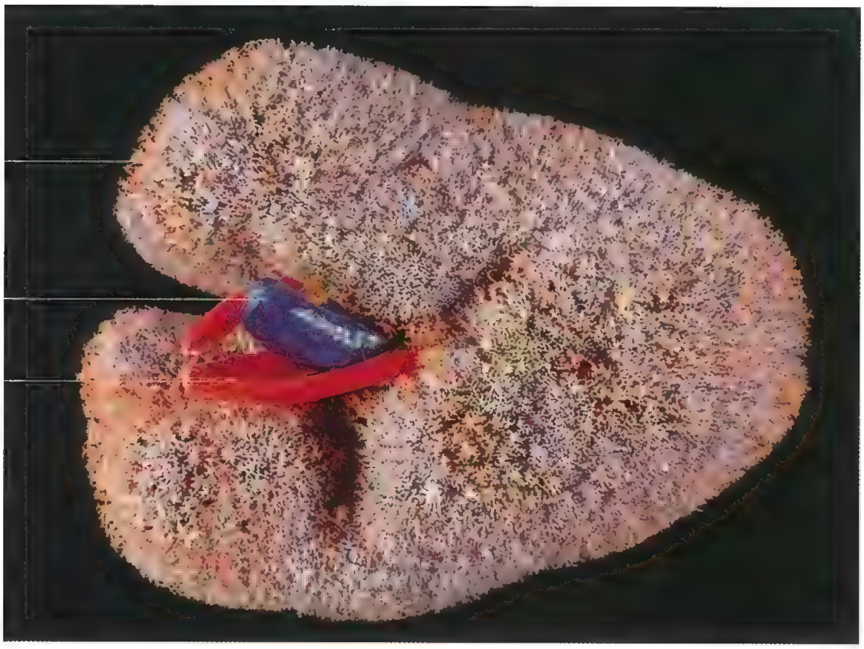

Fig. 9-16. Superficial blood vessels of the right kidney of a horse, corrosion cast (blue = stellate veins).

Fig. 9-17. Deep blood vessels of the left kidney of a horse, corrosion cast.

which are separated from each other by projections of renal tissue (pseudopapillae) (Fig. 9-18 and 19). Neighbouring recesses are also separated by the interlobar vessels.

The renal pelvis of the pig has a number of **short-stemmed calyces,** which embrace an equal number of renal papillae that protrude into the renal pelvis.

There is no renal pelvis in the ox. Instead the papilla of each medullary lobe fit into a **calyx** formed by the terminal branches of the ureter. These branches unite into two major channels, which converge from both poles of the kidney to form a single ureter (Fig. 9-20).

The **renal pelvis** of the horse consists of a **central cavity** and two large **recesses** (recessus terminales) that are directed towards the poles of the kidney (Fig. 9-21). Most of the papillary ducts open into the recesses. The mucosa of the renal pelvis produces a mucous secretion, which accounts for the proteins normally present in the equine urine (physiological albuminuria).

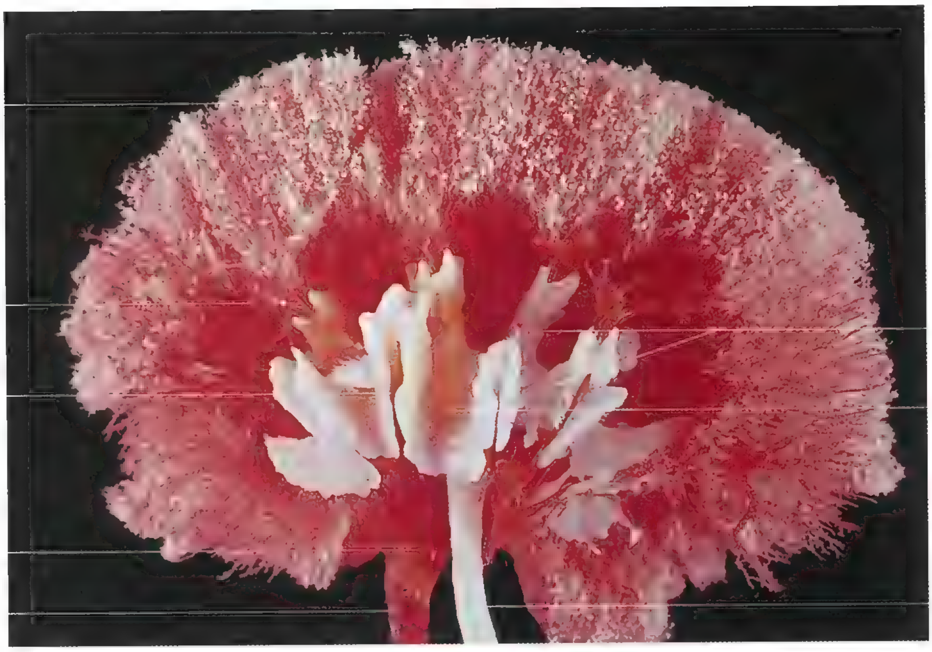

Fig. 9-18. Renal pelvis and renal arteries of a dog, corrosion cast.

Fig. 9-19. Renal pelvis of a dog, corrosion cast.

Ureter

The ureter is a muscular tube (Fig. 9-5 and 23), which passes caudally in the retroperitoneal space along the dorsal body wall. It can be divided into an **abdominal part** and a **pelvic part.** On reaching the pelvic cavity, it turns medially to enter the broad uterine ligament in the female and the mesoductus deferens in the male. The ureter ends by inserting into the dorsolateral surface of the urinary bladder within the lateral ligament of the bladder. In the male, it crosses dorsal to the corresponding deferent duct. The ureter enters the bladder obliquely close to the neck and runs intramurally between the muscular layer and the mucosa of the bladder for about 2cm before opening into the lumen of the bladder by means of two **slits** (ostium ureteris) (Fig. 9-24 and 25).

The length of the intramural course prevents reflux of urine into the ureter when the pressure is raised within the bladder, but does not hinder further filling of the bladder since the resistance is normally overcome by peristaltic contractions of the ureteric wall.

Fig. 9-20. Ureter of an ox with renal calices, corrosion cast.

Fig. 9-21. Renal pelvis of the left kidney of a horse, corrosion cast.

The wall of the renal pelvis and the ureter are composed of an external adventitia, a middle muscularis and an internal mucosa. The ureteral mucosa has a transitional epithelium (Fig. 9-23). In the horse the wall of the proximal portion of the ureter contains **mucous producing glands** (glandulae uretericae).

The **arteries of the renal pelvis** are derived from the **renal artery,** the arteries for the rest of the ureter are branches of the renal artery, the cranial vesical artery and the prostatic or vaginal artery. The ureteral arteries have venous counterparts.

The **ureteral lymphatics** drain into the **lumbar lymph nodes** situated along the aorta and into the **medial iliac lymph nodes.** The ureter receives **parasympathetic** and **sympathetic innervation.**

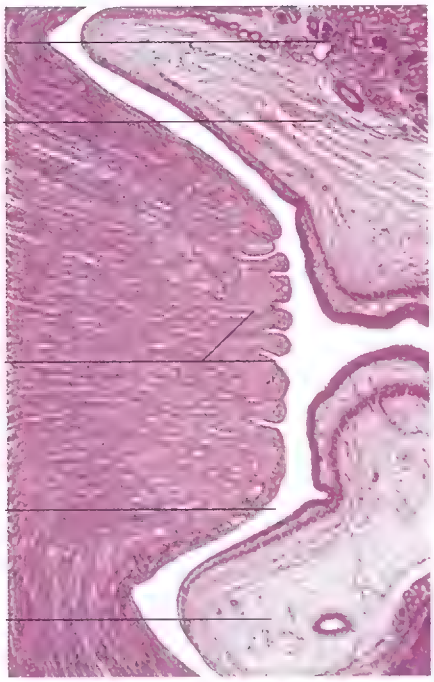

Fig. 9-22. Histological section of the renal crest and renal pelvis of a dog (Liebich, 2004).

Fig. 9-23. Histological section of the ureter of a pig (Liebich, 2004).

Urinary bladder (vesica urinaria)

The urinary bladder is a hollow **musculomembraneous organ** that varies in form, size and position depending on the amount of urine it contains. It is small and globular, when contracted and lies on the pubic bones. It extends into the abdomen in carnivores, but is confined to the pelvic cavity in larger animals. During filling it enlarges gradually and becomes pear-shaped.

The bladder can be divided into a **cranial vertex** (vertex vesicae), an **intermediate body** (corpus vesicae) and a **caudal neck** (cervix vesicae), which is continuous with the urethra (Fig. 9-6 and 25). The **bladder** is supported by double layers of peritoneum, which reflect from the lateral and ventral surface of the bladder to the lateral walls of the pelvic cavity and the abdominal floor. These peritoneal reflections are the **median ligament** (ligamentum vesicae medianum) and **lateral ligaments** (ligamenta vesicae laterales) of the bladder. In the foetus the median ligament contains the urachus, the stalk of the embryonic allantois and the paired lateral ligaments convey the umbilical arteries to the umbilicus.

The urachus and umbilical arteries rupture at birth; the remnant of the urachus is visible as a scar on the bladder vertex, while the umbilical arteries are transformed into the round ligaments, which are found in the free edge of the lateral ligaments and are only partly recede. The urachus may persist in some individuals.

The **lateral ligaments** of the bladder constitute the border between the pubovesical and the vesicogenital excavation.

The **median ligament** of the bladder divides the pubovesical excavation into left and right halves (Fig. 6-21).

Most of the surface of the bladder, except the caudal part of the neck of the bladder, is covered with peritoneum, which continues as the ligaments of the bladder onto the body walls. The bladder muscle (m. detrusor) is arranged in three layers that exchange muscle fibres (Fig. 9-25):

- Outer longitudinal layer,
- Middle circular layer,
- Inner longitudinal layer.

The **vertex** and **neck** are surrounded by loops of muscle bundles, which do not form a functional sphincter as formerly hypothesised. Recent research has shown that continence depends upon the tension passively exerted by the elastic elements within the mucosa and on the action of the striated urethra muscle (Fig. 9-25 and 27).

The bladder is lined by a **transitional epithelium.** The mucosa of the bladder is irregularly folded when the bladder is empty. These folds disappear during distension with the exception of two **folds** (plicae uretericae), which extend from the ureteral opening to the neck of the bladder, where they unite to form the **urethral crest,** which is continuous with the urethra. The **triangular area** bounded by these folds is termed the trigone of the bladder (trigonum vesicae) and is thought to have an enhanced sensitivity (Fig. 9-25).

The bladder receives its main **blood supply** from the **caudal vesical arteries,** which are branches of the vaginal or prostatic arteries. It is supplemented cranially by the reduced umbilical arteries.

The **lymphatics** of the bladder drain into the **iliosacral lymph nodes.** The urinary bladder receives **sympathetic** and

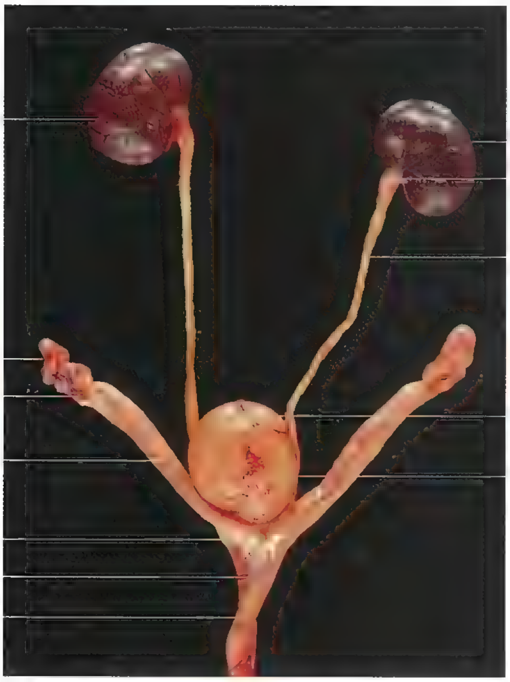

Fig. 9-24. Urogenital system of a cat, ventral aspect (König 1992).

parasympathetic innervation. Sympathetic fibres arise from the **hypogastric nerves,** which radiate from the caudal mesenteric ganglion into the **pelvic plexus.** Parasympathetic pelvic nerves are derived from the **pudendal nerve,** the ventral branch of the third sacral segment, and radiate in to the **pelvic plexus.** Parasympathetic fibres supply somatic innervation to the bladder muscle, sensory nerves are also routed through the pudendal nerve.

The bladder can be punctured in the dog and the cat just cranial to the rim of the pelvis. The needle should be advanced in a caudodorsal direction to avoid injuries when the bladder contracts.

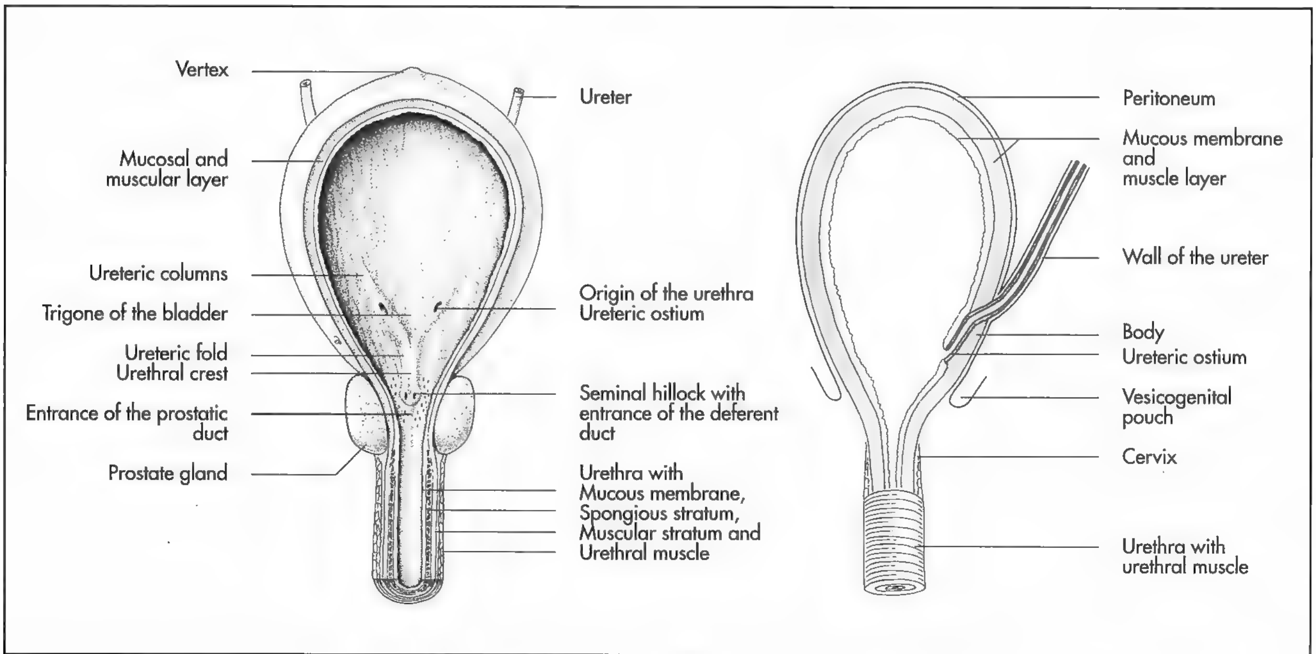

Fig. 9-25. Interior of the urinary bladder of the dog, ventral aspect (left), ureterovesical junction (right), schematic.

Fig. 9-26. Urethra of a dog within the penis with the penile bone, ventral aspect, corrosion cast.

Fig. 9-27. Urinary bladder and origin of the urethra, corrosion cast.

Urethra (urethra)

In the **female animal** the urethra exclusively serves to convey urine, while in the male animal it carries urine, semen and seminal secretions. The female urethra extends caudally on the pelvic floor ventral to the reproductive tract. It passes obliquely through the wall of the vagina and opens with the **external urethral opening** (ostium urethrae externum) ventrally at the junction between vagina and vestibule. The length and diameter of the urethra varies considerably between the domestic mammals. It is short and wide in the horse and comparatively long in the dog, were it opens on a small elevation flanked by two grooves. In the cow and sow the urethralis muscle encloses the suburethral diverticulum, which opens together with the urethra into the vagina. This arrangement can cause difficulties during catheterisation. The structure of the female urethra is continuous with that of the bladder.

The **male urethra** extends from an internal opening at the bladder neck to an external opening at the end of the penis. It is divisible into a:

- **Pelvic part** (pars pelvina),
  - Preprostatic portion (pars praeprostatica),
  - Prostatic portion (pars prostatica) and
- **Penile part** (pars penina).

The **pelvic part** of the urethra begins at the internal opening at the bladder neck. Its **preprostatic portion** extends from the internal opening to the **seminal hillock** (colliculus seminalis), an oval enlargement of the urethral crest, which protrudes into the lumen of the urethra. It is flanked by the slitlike openings of the deferent ducts. The **prostatic portion** is joined by the **deferent** and **vesicular ducts** and passes through the **prostate gland.** The **penile portion** of the urethra begins at the ischial arch and is described with the penis in the following chapter.

The **urethral wall** contains a **venous plexus** in its submucosa, which has erectile properties that aid continence. The urethra is surrounded by the **striated urethral muscle** over most of its length. Caudally the muscle fibres are present on the ventral and lateral surface. Contraction of these muscle bundles closes the external opening of the urethra. Voluntary control of the urethral muscle is provided by somatic fibres of the **pudendal nerve,** which also contains **sympathetic** and **parasympathetic fibres.**

Clinical terms related to the urinary system:
Nephritis, pyelonephritis, pyelography, cystoscopy, urography, urolithiasis, urethritis, urethrography, urethrostomy, urethrocystography.

10 Male genital organs (organa genitalia masculina)

C. Červeny, H. E. König and H.-G. Liebich

The male genital system comprises the organs that are involved in the development, maturation, transport and deposition of the **male gametes** (spermatozoa). It consists of the paired testes, the convoluted duct of the **epididymis** (ductus epididymidis), the **deferent duct** (ductus deferens), the **urethra** (pars pelvina urethra) and the **accessory glands** (glandulae genitales accessoriae). The testes produce both sperm and hormones. The epididymis, stores spermatozoa during maturation before they pass to the deferent duct and the urethra. The accessory glands also drain into the urethra and contribute to the volume of semen. The distal part of the urethra forms the combined path for the passage of both urine and semen. The penis is the male copulatory organ and deposits the semen within the female reproductive tract (Fig. 10-1 to 5).

Testis (orchis)

The testis, or male gonads (Greek orchis, Latin testis), are paired organs, which take their embryological origin from the gonadal primordium on the medial of aspect of the mesonephros in the lumbar region, in a similar manner to the ovaries in females. At a later stage of embryological development, the male gonads migrate from their developmental position within the abdominal cavity into the **vaginal process** (processus vaginalis), covered by the **scrotum.** This process is termed the **descent of the testes** (descensus testis) and is dependent on the gubernaculum testis. This is a mesenchymal cord enfolded in peritoneum, which extends from the testis, through the inguinal canal into the preformed vaginal process.

In the first phase of **testicular descent,** the gubernaculum increases in length and diameter, expanding beyond the inguinal canal thus dilating it. During the second phase, it regresses thus accommodating the testis within the **vaginal process.** The process of migration of the testes is the result of increases in intra-abdominal pressure and the pull of the gubernaculum that draw the testes toward the inguinal region. In the stallion and boar, fibres of the gubernaculum extend into the **deep layer** (tunica dartos) of the scrotum. This is of clinical importance since pulling on the scrotum can help to expose a retained testis from the inguinal canal.

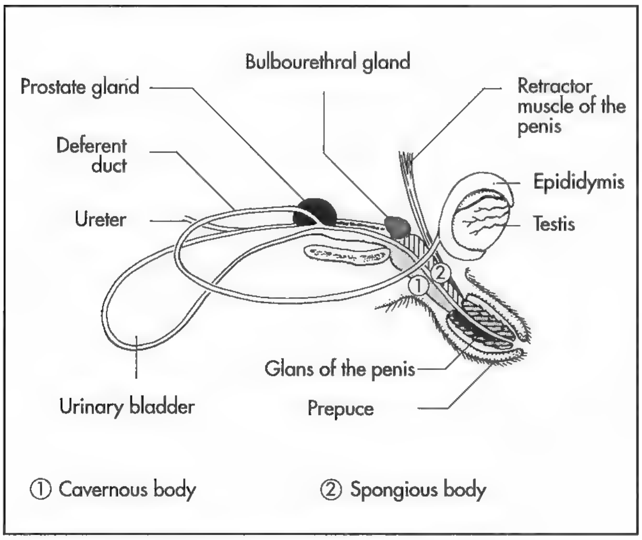

Fig. 10-1. Genital organs of the male cat, schematic.

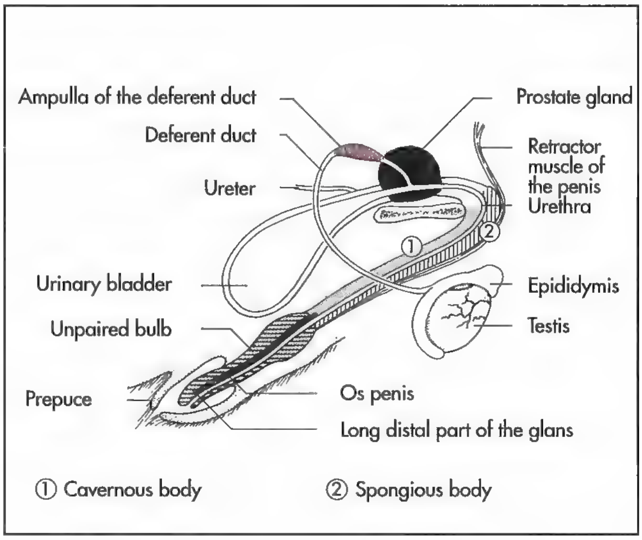

Fig. 10-2. Genital organs of the male dog, schematic.

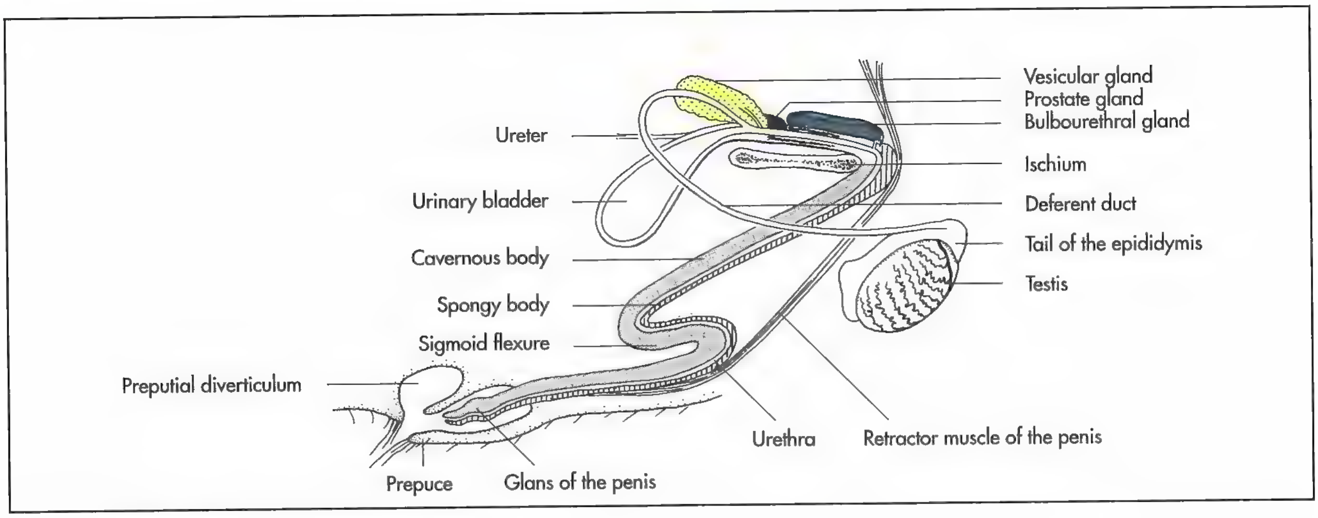

Fig. 10-3. Genital organs of the boar, schematic.

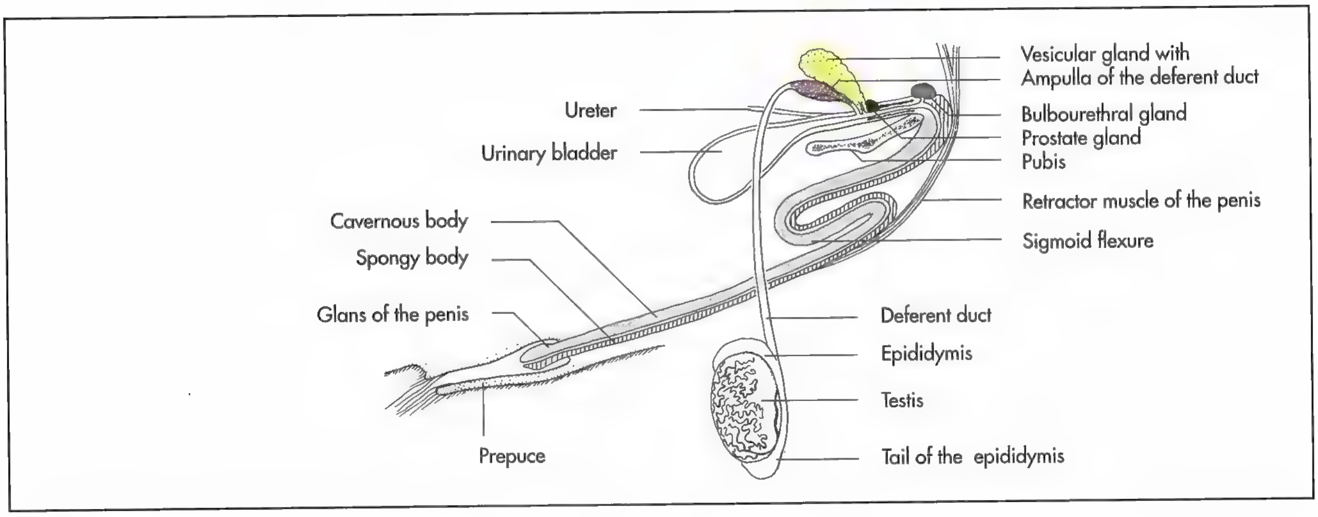

Fig. 10-4. Genital organs of the bull, schematic.

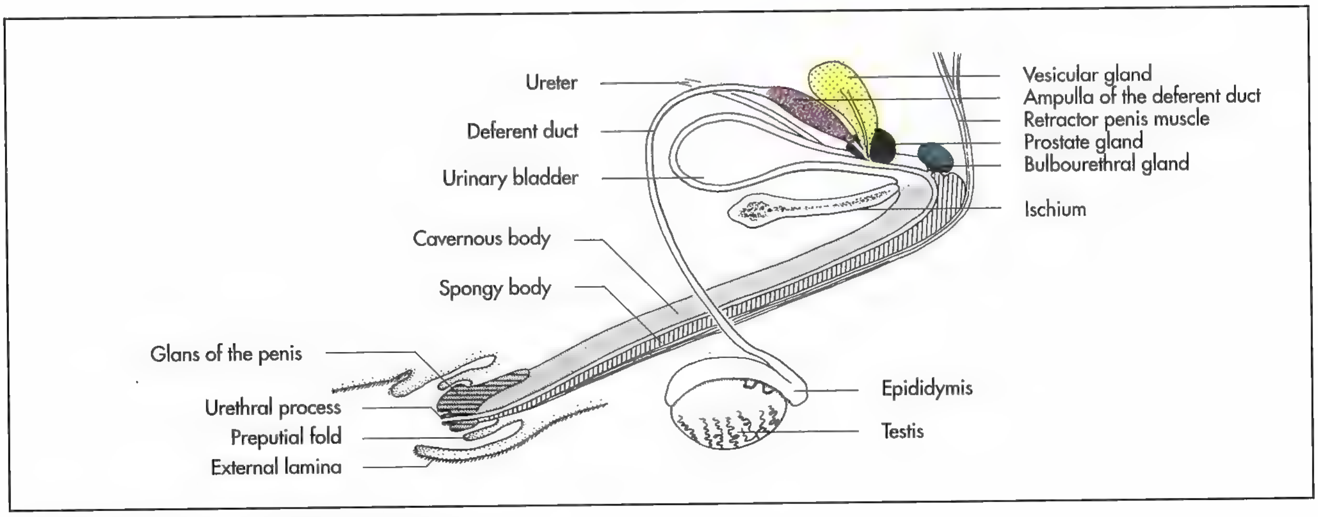

Fig. 10-5. Genital organs of the stallion, schematic.

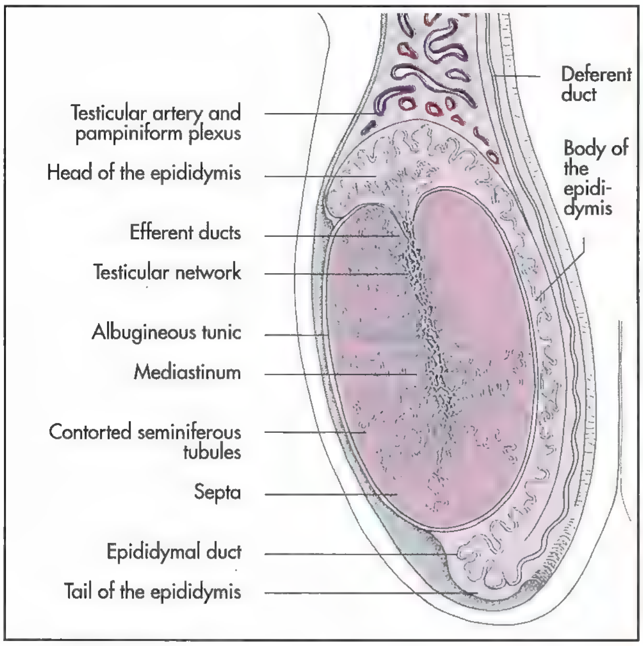

Fig. 10-6. Testis, epididymis and defernt duct of the bull, median section, schematic.

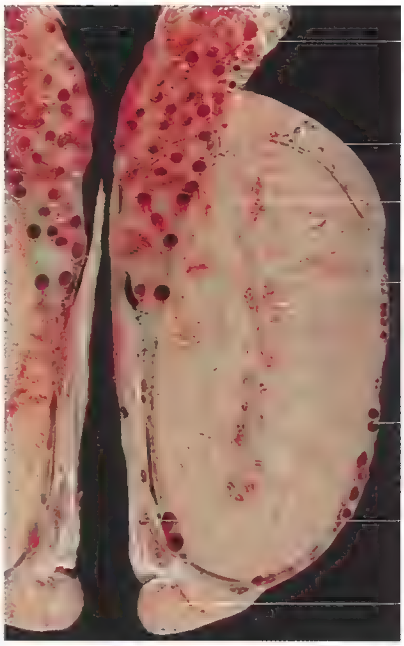

Fig. 10-7. Testis of a bull, median section, testicular artery injected.

Testicular descent is vital for the production of the **male gametes** (spermatogenesis) in the domestic mammals, since the scrotal position decreases the temperature of the testes compared to the body temperature. Failure of one or both testes to descend is termed **cryptorchidism** and is thought to have a hereditary basis. Therefore, cryptorchids should not be used for breeding.

In a few species, such as the elephant, the testes remain within the abdomen throughout life and spermatogenesis occurs at this temperature. Many smaller mammals such as rodents, exhibit periodic changes in which the testes descend into the scrotum during the breeding season after which they return to the abdomen.

Structure of the testis

The surface of the testis is invested by a dense **fibrous capsule** 1–2mm thick (albugineous tunic, tunica albuginea) (Fig. 10-6 and 11), which is composed of collagenous fibres and contains larger blood vessels (a. testicularis, v. testicularis). These are visible on the surface of the testes in a pattern, characteristic of each species. The **visceral vaginal** tunic is a serous membrane continuous with the peritoneum that covers the **fibrous capsule** and gives a smooth appearance to the surface of the testis.

The parenchyma of the testis is normally under pressure. Consequently, any significant expansion raises the intratesticular pressure and produces severe pain as seen with inflammation (orchitis). The connective tissue components of the testis are arranged as follows, from the outside to the inside:

- Fibrous capsule (albugineous tunic, tunica albuginea),
- Septa (septula testis),
- Mediastinum (mediastinum testis).

The capsule detaches **septa** (septula testis), which radiate into the testis dividing the parenchyma in pyramid-shaped **lobules** (lobuli testis) (Fig. 10-6 and 11). These septa converge centrally to form the mediastinum of the testis. The mediastinum may be axial or slightly displaced toward the epididymis. The parenchyma of the testis is composed of:

- Contorted seminiferous tubules (tubuli seminiferi contorti),
- Straight seminiferous tubules (tubuli seminiferi recti),
- Spaces within the mediastinum (testicular network, rete testis) and
- Efferent ducts (ductuli efferentes).

Each testicular lobule includes between two and five **contorted tubules,** which are the site of spermatogenesis. The wall of these tubules contains **spermatogenic cells** and **sustentacular** (Sertoli-)cells, which have supporting and hormone-producing properties. They are responsible for the regulation of spermatogenesis, supplying the nutrients to spermatogenic cells during the different stages of development and the release of spermatozoa into the lumen of the tubule (Fig. 10-8 and 9). A more detailed description can be found in histology and embryology textbooks.

Each **contorted seminiferous tubule** is looped, so that it opens with both ends into a network of confluent spaces within the **mediastinum,** called the **rete testis** (Fig. 10-6 and 11). Before entering the rete testis, the ends of the seminiferous tu-

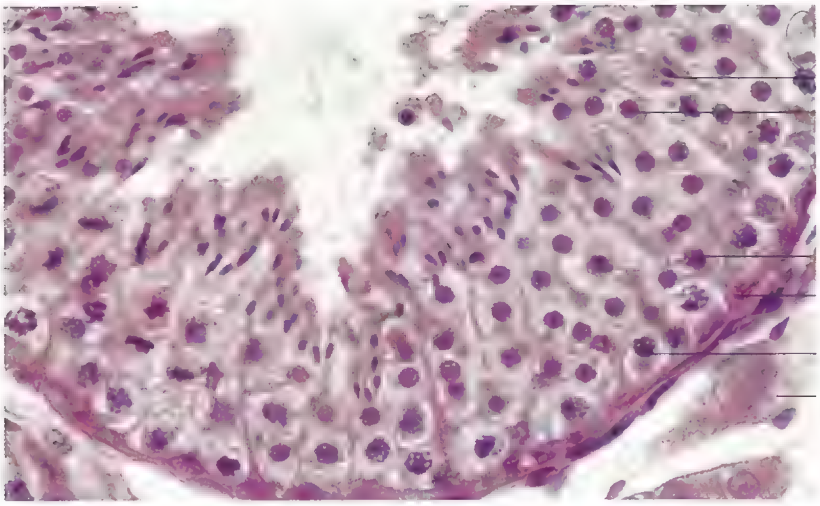

Fig. 10-8. Histologic section of the wall of a contorted seminiferous tubule of a bull.

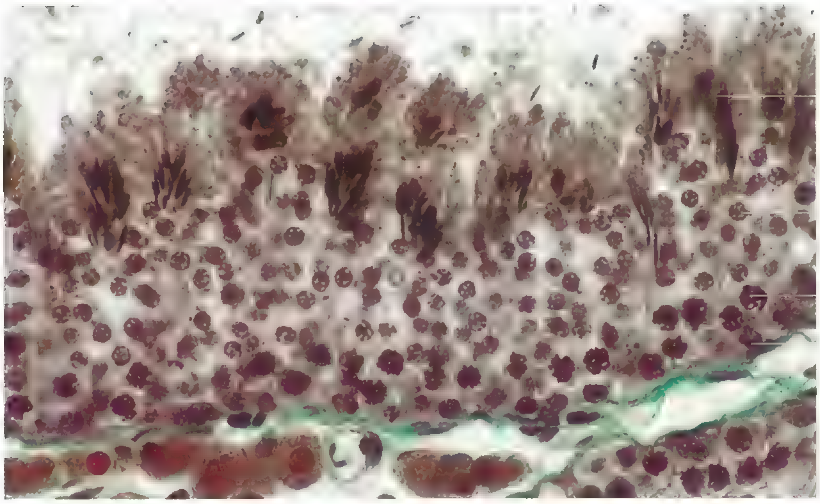

Fig. 10-9. Histologic section of the wall of a contorted seminiferous tubule of a bull.

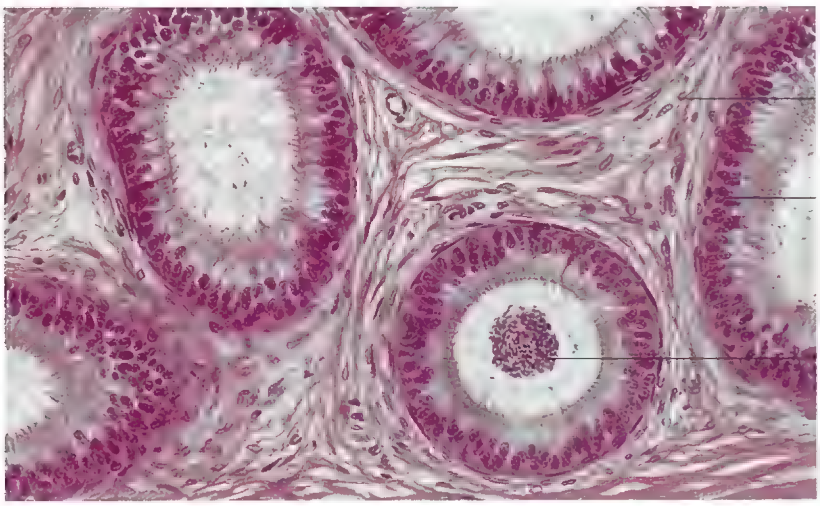

Fig. 10-10. Histologic section of the epididymal duct of a bull.

Fig. 10-11. Histologic section of the testis and epididymis of a bull.

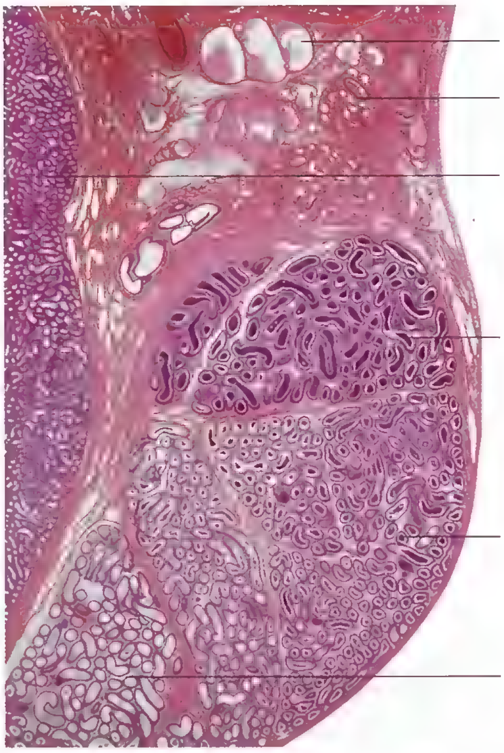

Fig. 10-12. Histologic section of the head of the epididymis of a bull.

bules straighten out to become the **straight seminiferous tubules** (tubuli seminiferi recti). The interstitial tissue filling the space between the tubules contains **Leydig-cells,** which are the principal producers of the androgenic steroidal hormones, such as testosterone. Each rete testes is drained by eight to twelve **convoluted efferent ducts** that perforate the fibrous capsule to enter into the head of the epididymis (Fig. 10-6).

Epididymis

The epididymis is firmly attached along the testis and consists of the coils of the elongated convoluted tubules, which are held together by connective tissue. It can be divided into three parts (Fig. 10-6 and 7):

- Head (caput epididymidis),
- Body (corpus epididymidis),
- Tail (cauda epididymidis).

The **head of the epididymis** is firmly attached to the testicular capsule and receives the **efferent ducts** of the testis. Immediately after entering the epididymis the efferent ducts join to form the **duct of the epididymis** (Fig. 10-12). The convoluted ducts form the **body of the epididymis,** held in place by a double layer of serosa. The space between the body of the epididymidis and the testis is termed the **testicular bursa** (bursa testicularis).

The **epididymal duct** continues as the **tail of the epididymis.** It is attached to the caudal extremity of the testis by the **proper ligament of the testis** (ligamentum testis proprium) and to the vaginal process by the **ligament of the tail of the epididymis** (ligamentum caudae epididymidis). This ligament extends fibres into the deep layer of the scrotum, which are especially well developed in the stallion and the boar. The duct of the epididymis emerges at its tail and continues as the **ductus deferens.**

In the **duct of the epididymis,** spermatozoa mature, testicular fluid is absorbed, cell fragments undergo phagocytosis and nutrients for the spermatozoa are secreted. Spermatozoa are stored in the tail of the epididymis until ejaculation.
Length of the epididymal duct in the domestic species:

- Horse: 2 – 81 m
- Bull: 40 – 50 m
- Ram: 47 – 52 m
- Boar: 17 – 18 m
- Dog: 5 – 8 m
- Cat: 4 – 6 m

Deferent duct (ductus deferens)

The **deferent duct** is the direct continuation of the duct of the epididymis. It originates as the undulating part of the tail of the epididymis and gradually straightens as it passes along the medial border of the testis. It ascends within the **spermatic cord** (funiculus spermaticus) and enters the abdominal cavity through the inguinal canal. It forms a cranially convex loop within a **fold of peritoneum** (mesoductus deferens) and passes under the ureter as it reaches the dorsal surface of the bladder. It perforates the prostate gland, to open in the proxi-

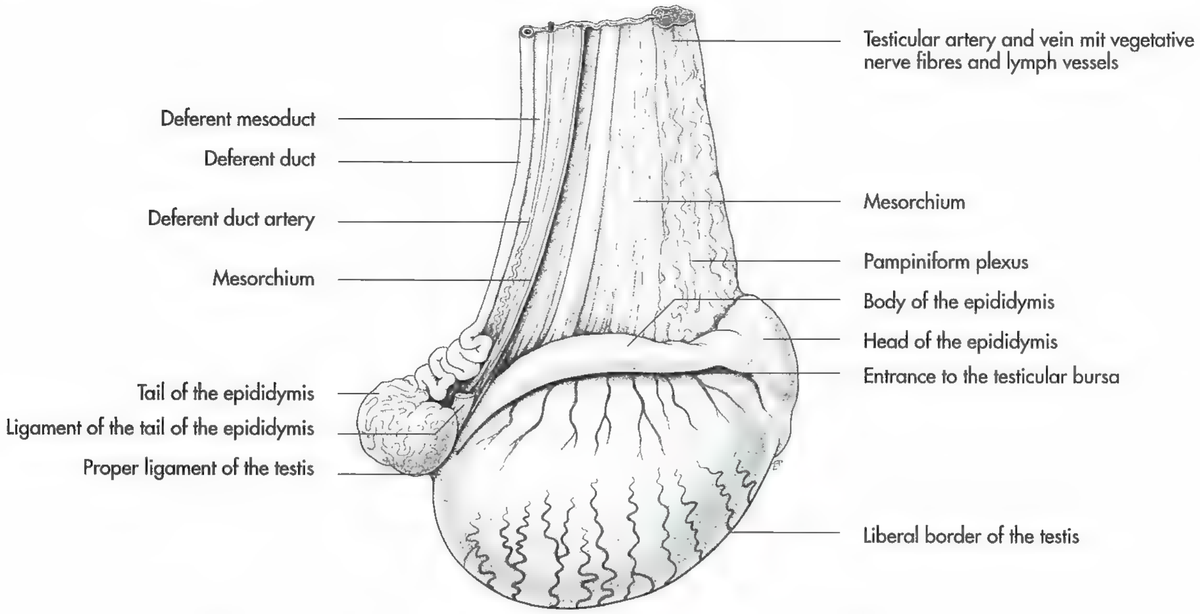

Fig. 10-13. Right testis, epididymis and spermatic cord of a stallion, lateral aspect, schematic.

mal part of the urethra at the **seminal hillock** (colliculus seminalis) (Fig. 9-25). The terminal part of the deferent duct is thickened to form the **ampulla of the deferent duct** by the ampullary gland. In the dog, no distinct ampulla is obvious, but there is a glandular part at the end of the deferent duct.

In the horse and in ruminants the deferent duct is joined by the **excretory duct** (ductus excretorius) of the vesicular gland near to its termination. The shared passage of these two ducts is known as the **ejaculatory duct** (ductus ejaculatorius).

Investments of the testis

The investments of the testis not only cover the testis, the epididymis and parts of the spermatic cord and are moulded around these organs (Fig. 10-14). The different layers of the testicular investments correspond to the layers of the abdominal wall. They are the following layers:

Scrotum:
- External skin,
- Fibromuscular subcutaneous layer (tunica dartos),
- Double-layered external spermatic fascia (fascia spermatica externa), detachments of the abdominal fasciae,
- Cremaster muscle, a detachment of the internal oblique muscle of the abdomen, along with its fascia,

Vaginal process:
- Internal spermatic fascia (fascia spermatica interna),
- Parietal layer (lamina parietalis) of the vaginal tunic (tunica vaginalis).

The **external skin,** the **subcutaneous tunica dartos** and the **external spermatic fascia** form the **scrotum.** The internal spermatic fascia and the parietal layer of the vaginal tunic form the **vaginal process** (processus vaginalis), an expansion of the peritoneal cavity within the scrotum. The vaginal process extends into the right and left compartments of the scrotum, which are divided by a septum formed by the skin and the subcutaneous layer of the scrotum. The **scrotal septum** (septum scroti) encloses the testes separately and is marked externally as a **groove** (raphe scroti) (Fig. 10-14).

The **scrotal skin** is usually hairless, except in the cat and certain breeds of sheep, where it is covered in hair. It has a generous supply of both sweat and sebaceous glands and adheres firmly to the underlying **tunica dartos.** Internal to the tunica dartos is a thin layer of **soft tissue** (fascia subdartoica). The tunica dartos has several smooth muscle fibres, which contract to tighten and retract the scrotum, thereby contributing to the temperature regulation of the testis. The tunica dartos is especially well developed in the ox, where it can be up to 10mm thick.

The **external spermatic fascia** is detached from the **deep** and the **superficial fascia of the abdomen** at the scrotum and is divided into a deep and a superficial layer. The two layers of the external spermatic fascia and the internal spermatic fascia and the vaginal tunic are connected by loose connective tissue. This loose intermediate stratum allows movement of the vaginal process within the scrotum. It is of clinical significance, since it facilitates castration by a closed technique, whereby the vaginal tunic is ligated with the blood vessels and ductus deferens.

The **cremaster muscle** is the detachment of the **internal oblique muscle of the abdomen** at the level of the deep inguinal ring (Fig. 10-14). It covers part of the vaginal process and is covered by a thin layer of loose connective tissue (fascia cremasterica) (Fig. 10-14 and 18). On contraction,

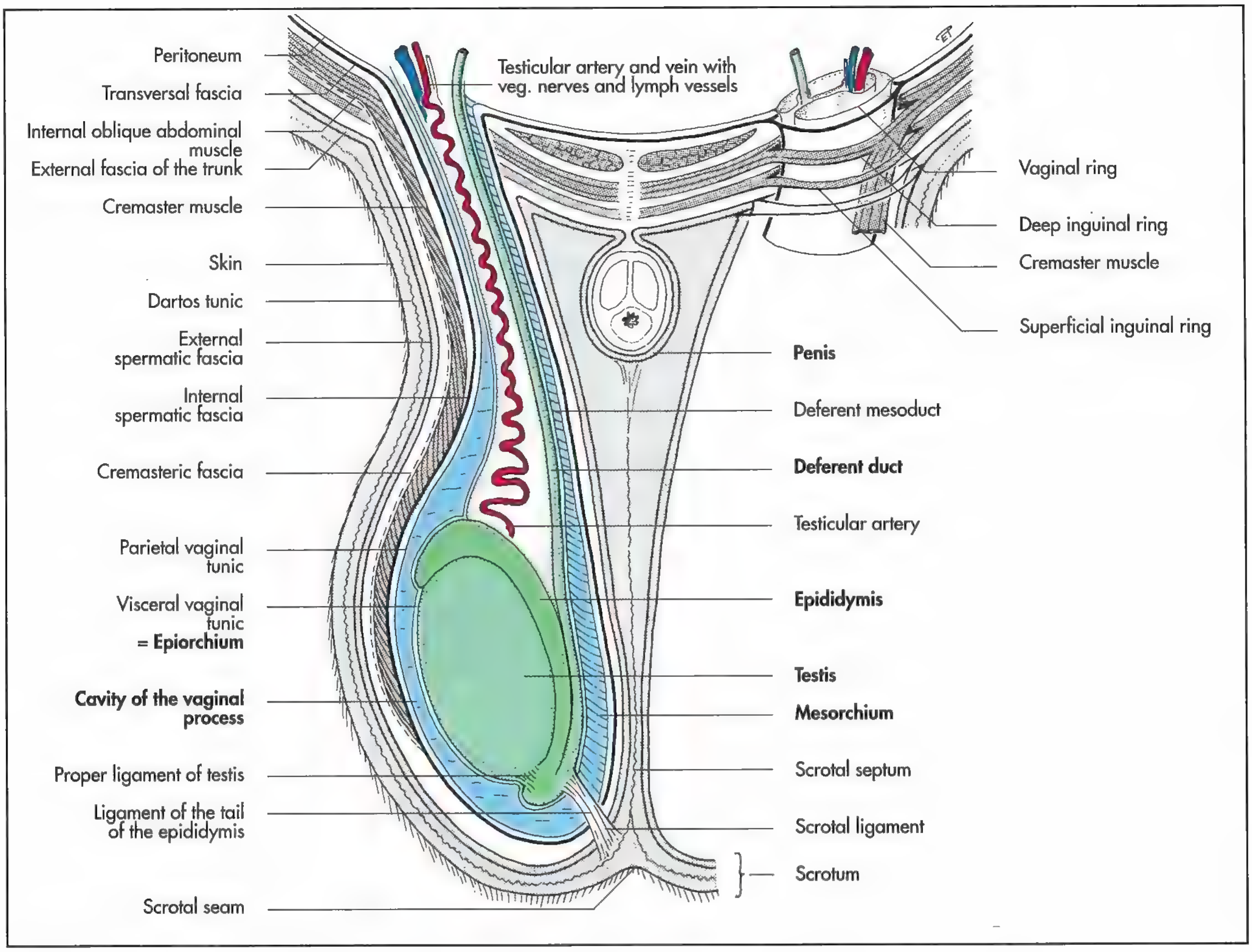

Fig. 10-14. Investments of the testis and spermatic cord of the bull, schematic.

it retracts the scrotum with its contents toward the inguinal region. In rodents it embraces the vaginal process in a spoon-like fashion and thus the testes can be withdraw into the abdomen through the large inguinal canal.

Vaginal process (processus vaginalis) and spermatic cord (funiculus spermaticus)

The vaginal process is formed by the **transverse fascia** and the **peritoneum** as an evagination of the abdominal cavity through the inguinal canal. It encloses the **vaginal cavity** (cavum vaginale) and is formed before the embryological descent of the testes place (Fig. 10-14). The shape of the vaginal process resembles a bottle with a narrow proximal part, the length of which depends on the position of the scrotum and a wider distal part, which moulds to the organs it encloses.

The **vaginal cavity** communicates with the abdominal cavity through the **vaginal opening** (ostium vaginale) located within the internal opening of the inguinal canal. Normally it contains a very small amount of peritoneal fluid, which helps to reduce friction between the wall and the enclosed organs. Occasionally a loop of intestine or part of the omentum herniates into the vaginal process. This condition (hernia inguinalis) is more common in species with a wide vaginal ring, such as the horse and the pig. Since it appears to be hereditary in the pig, animals that develop this condition should not be used for breeding.

The narrow proximal part of the vaginal process surrounds the **spermatic cord** (funiculus spermaticus), which is composed of the deferent duct and the testicular vessels and nerves, along with their serous membranes. The spermatic cord is attached by the mesofuniculus, which is continuous distally with the mesorchium (Fig. 10-14 and 18). The deferent duct is enclosed within a fold of the **mesofuniculus.** The vascular plica, also termed proximal mesorchium attaches to the epididymis and continues from there onto the testis as the distal mesorchium.

Position of the scrotum

The position and orientation of the scrotum varies considerably among the domestic mammals (Fig. 10-1 to 5). The scrotum is located in the inguinal region in the horse and the dog, below the **inguinal region** in ruminants, perineal in pigs and **subanal** in cats. In ruminants the testes are carried with their long axes vertically, thus they possess a deep and pendu-

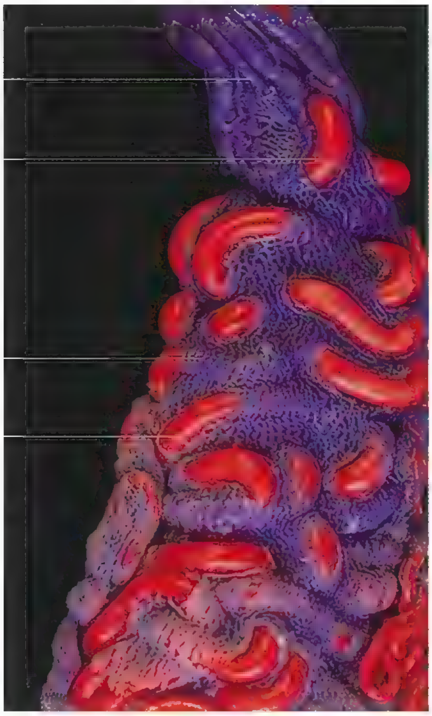

Fig. 10-15. Testicular artery and vein within the spermatic cord of a ram, corrosion cast.

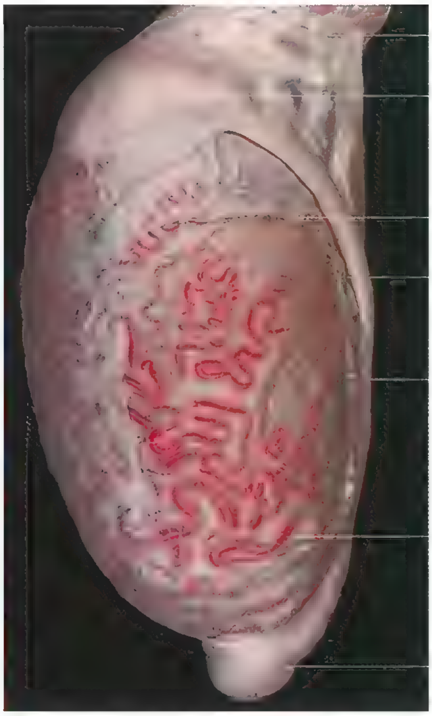

Fig. 10-16. Testis of a bull after injection of the blood vessels.

lous scrotum. The testes are orientated with their long axis horizontally in the horse and dog while in the pig and cat, they are angled towards the anus.

Blood supply, lymphatic drainage and innervation of the testis and its investments

The **testicular artery** (a. testicularis) branches directly from the abdominal aorta and passes along the abdominal wall, suspended within the vascular plica together with the testicular vein. Within the spermatic cord, the testicular artery is extremely convoluted. In the ox about 7m of artery is packed within 10 cm of spermatic cord (Fig. 10-15 and 16). The testicular artery extends branches to supply the epididymis (rami epididymales) and the original part of the deferent duct (rami ductus deferentis).

The **testicular veins** form a very elaborate **mesh-like plexus** (plexus pampiniformis) around the arterial coils. **Arteriovenous anastomoses** are present between the testicular artery and the surrounding veins within the spermatic cord (Fig. 10-15). The pampiniform plexus is ultimately reduced to a single vein (v. testicularis), which drains into the caudal vena cava. The extensive contact between the vessels within

Fig. 10-17. Testis of a boar after injection of the lymph vessels (green) and the superficial loops of the testicular artery (red) (courtesy of PD Dr. J. Maierl, Munich).

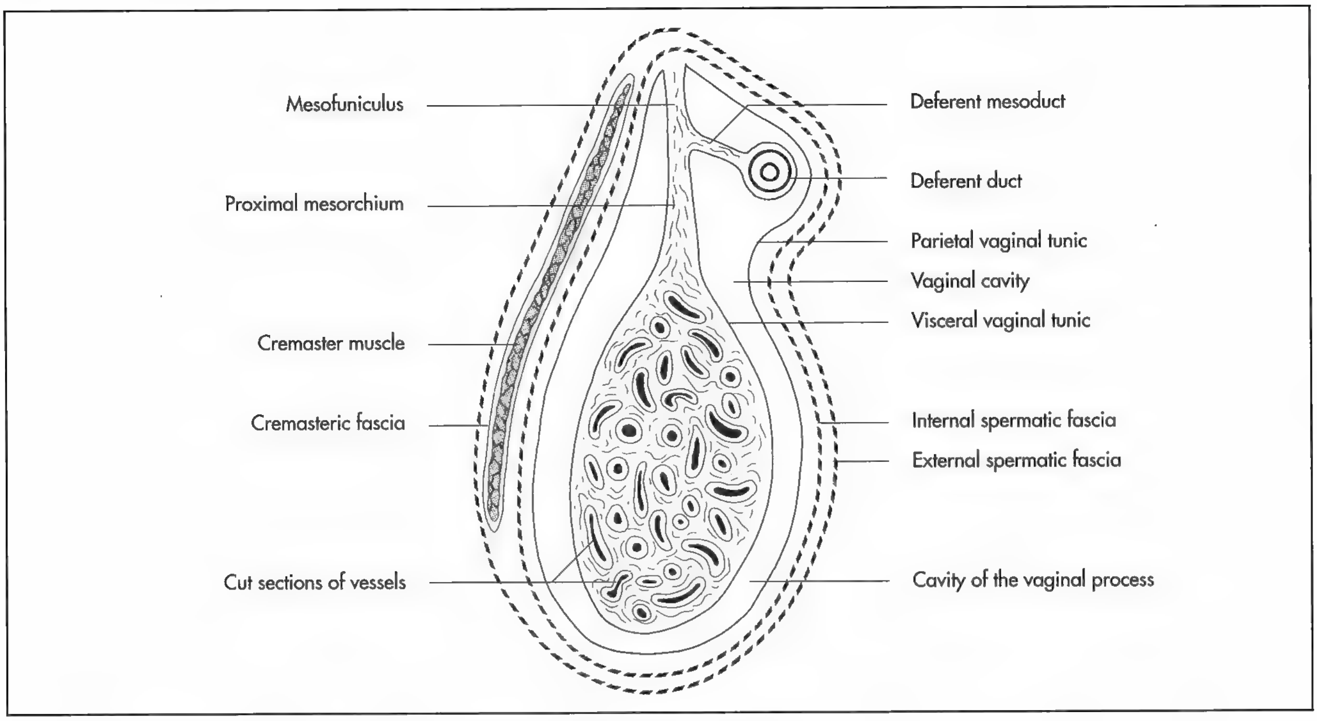

Fig. 10-18. Poximal part of the vaginal process, transverse section (Schaller, 1992).

the spermatic cord cools the blood within the artery on its descent to the testis.

The **lymphatics of the testis** (Fig. 10-17) drain into the **lumbar aortic lymph nodes** and the **medial iliac lymph nodes.** The lymph conveys a substantial fraction of the hormones produced by the testis. In the case of testicular cancer, it is essential to remove the affected testis as soon as possible, since access to the draining lymph nodes is impossible, due to their location on the dorsal wall of the abdomen and pelvis.

The testes receive **nervous supply** from the autonomic nervous system. **Parasympathetic fibres** are derived from the vagal nerve and the pelvic plexus; **sympathetic fibres** arise from the caudal mesenteric plexus and the pelvic plexus.

The **investments of the testis** are vascularised by the **external pudendal artery** and **vein** (a. et v. pudenda externa). Lymphatics drain into the scrotal or superficial inguinal lymph nodes. Nerve supply is provided by the ventral branches of the lumbar nerves. The iliohypogastric nerve, the ilioinguinal nerve and the genitofemoral nerve contribute to their innervation.

Urethra

The male urethra extends from the **internal urethral opening** (ostium urethrae internum) at the caudal end of the neck of the bladder to the external **urethral opening** (ostium urethrae externum) at the free extremity of the penis. Based on its location it can be divided into a **pelvic portion** (pars pelvina) and a **penile portion** (pars penina).

The pelvic portion can be further subdivided into a proximal preprostatic part, that carries urine and a prostatic part, which is joined by the deferent duct and the vesicular or combined ejaculatory duct.

The preprostatic portion carries a **dorsal crest** (crista urethralis), which protrudes into the lumen and ends in a thickening (colliculus seminalis). The colliculus marks the openings of the deferent ducts (in the horse and in ruminants the combined ejaculatory ducts) and is flanked by the much smaller openings through which the many **prostatic ducts** (ductuli prostatici) discharge. On leaving the pelvic cavity, the urethra is surrounded by highly vascular tissue and continues as part of the penis.

Accessory genital glands (glandulae genitales accessoriae)

The accessory genital glands are located along the pelvic portion of the urethra. Their presence varies between the species and can include all or some of the following (Fig. 10-1 to 5 and 19 to 21):

- Ampullary gland (gl. ampullae),
- Vesicular gland (gl. vesicularis),
- Prostate gland (prostata) and
- Bulbourethral gland (gl. bulbourethralis).

The bull and stallion possess the **full set of accessory glands.** The boar has **vesicular, prostate** and **bulbourethral glands.** In the cat, the **ampullary, prostate** and the **bulbourethral glands** are present, while in the dog only the **ampullary** and the **prostate glands** are present.

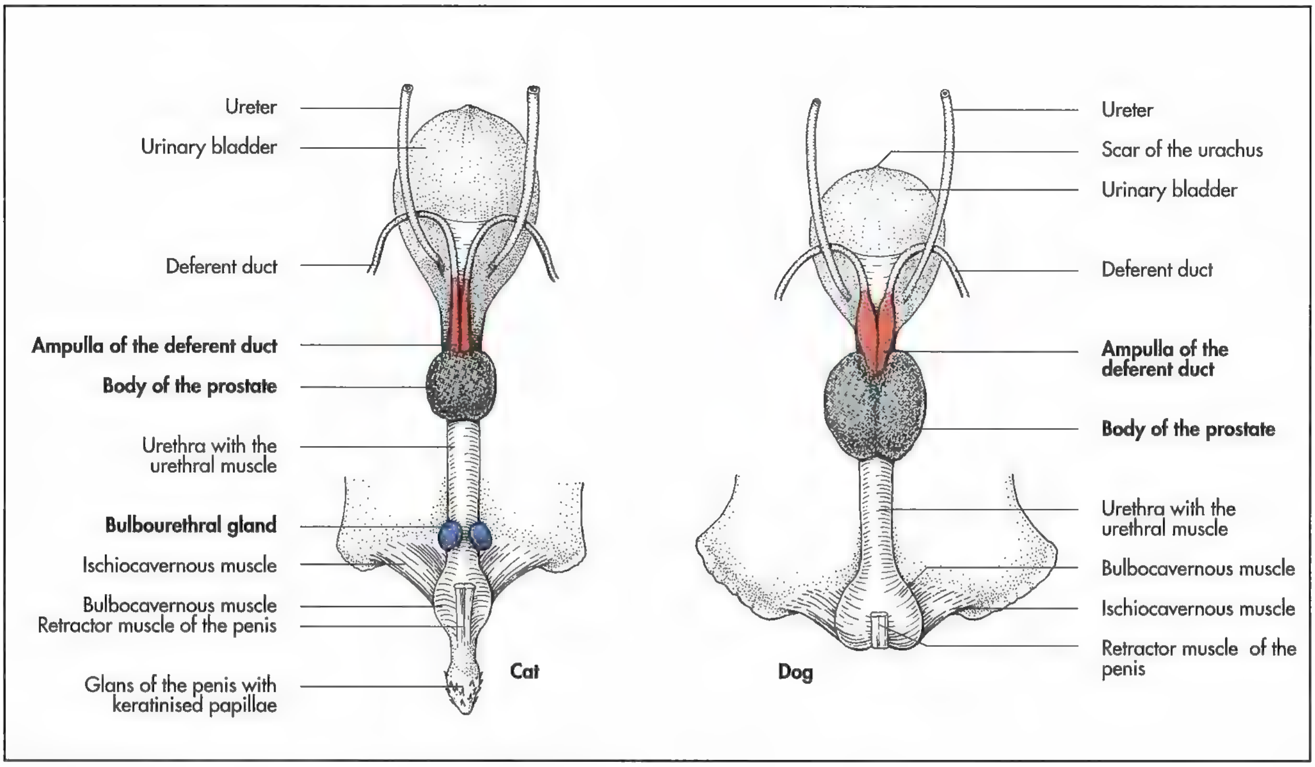

Fig. 10-19. Accessory genital glands of the cat and dog, schematic.

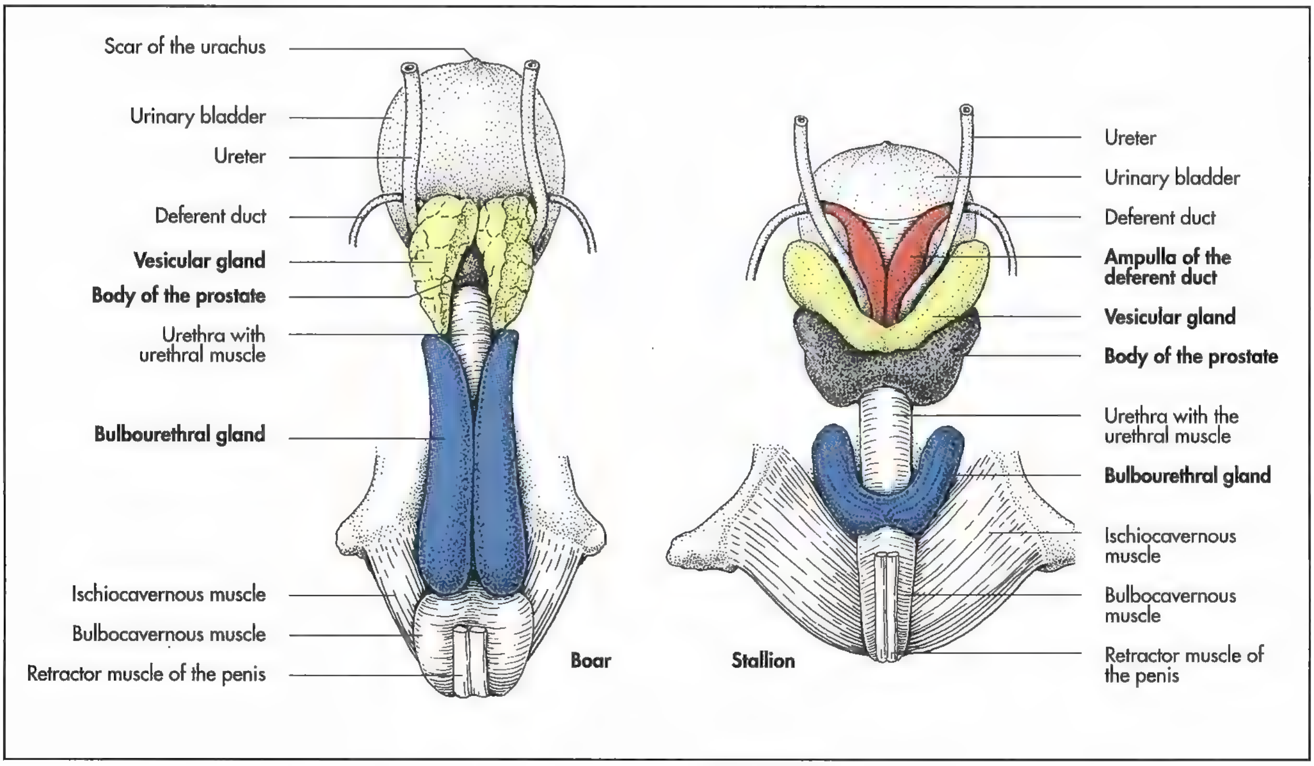

Fig. 10-20. Accessory genital glands of the boar and stallion, schematic.

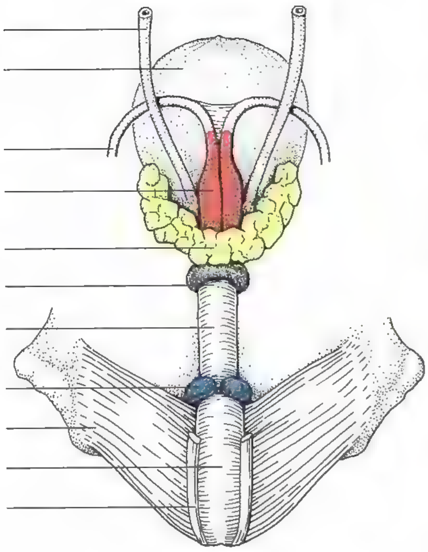

Fig. 10-21. Accessory genital glands of the bull.

The ampullary gland surrounds the terminal part of the deferent duct and is described earlier in this chapter.

Vesicular gland (glandula vesicularis)

The paired vesicular glands are present in all domestic mammals except the dog and the cat (Fig. 10-3 to 5 and 20 and 21). In ruminants and the horse, its **excretory duct** (ductus excretorius) joins the deferent duct shortly before its termination and this short, common passage is referred to as the **ejaculatory duct** (ductus ejaculatorius). In the boar, the vesicular glands open separately into the urethra next to the **seminal colliculus.**

The vesicular gland of the horse is a relatively large, hollow organ with a thick muscular wall and a smooth surface. In the bull and the boar, the surface is irregular. The vesicular gland is especially well developed in the boar, in which it has a characteristic pyramidal shape. In the bull, this gland can be palpated transrectally.

Prostate gland (prostata)

The prostate is present in all domestic mammals (Fig. 10-1 to 5 and 19 to 22). In some it consists of two parts, one diffusely spread within the wall of the **pelvic urethra** (pars disseminata), the other a compact **body** (corpus prostatae) located external to the urethra.

The horse has only the compact part, the small ruminants have only the disseminated part. The bull has both parts, but the compact part is rather small and flat. In the dog and cat, the disseminated part is vestigial, but the compact part is large and globular. It is so extensive in these species, that it entirely surrounds the urethra in the dog and almost so in the cat. Hypertrophy of the prostate gland is relatively common in older dogs and can lead to obstipation due to pressure from the enlarged prostate onto the rectum.

Bulbourethral gland (glandula bulbourethralis)

The paired bulbourethral gland (Fig. 10-2 to 5 and 19 to 21) is found in all domestic mammals other than the dog. It lies on the dorsal aspect of the pelvic urethra close to its pelvic exit. It has the size of a walnut in the stallion and that of a cherry in the bull. In the cat, it is very small and spherical. It is very substantial in the boar, where it is cylindrical and extends along the whole of the pelvic portion of the urethra. In castrated boars it is considerably smaller, as such its size can be used an indicator of recent castration.

All accessory genital glands have well **developed soft-tissue capsules** and **internal septa,** which are rich in smooth muscle fibres. These muscle fibres are innervated by the autonomic nervous system and are responsible for expelling the secretion of the glands. Testosterone has a positive effect on the production of secretions, which contain **fructose** and **citrate** for the nutrition, transportation and protection of the spermatozoa. It also enhances movement of the spermatozoa and acts as a physiological buffer against the acid environment within the vagina.

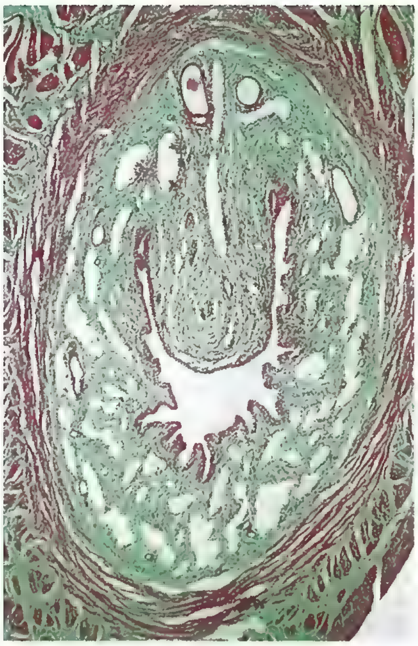

Fig. 10-22. Histologic section of the ampullary gland of a bull.

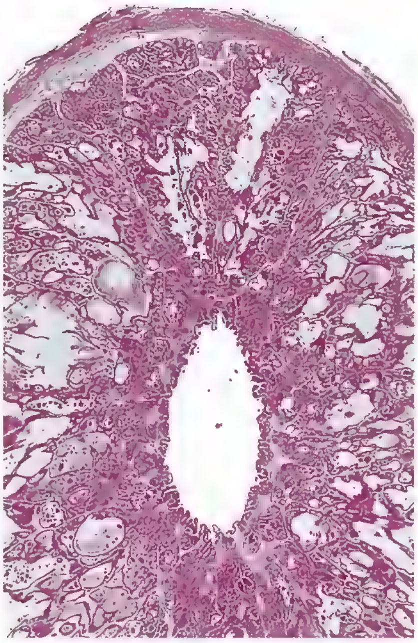

Fig. 10-23. Histologic section of the vesicular gland of a bull.

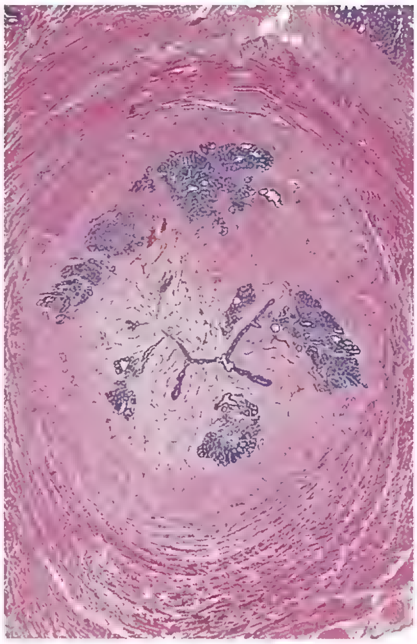

Fig. 10-24. Histologic section of the prostate of a dog.

Penis

The penis originates as two crura from the ischial arch. The crura converge to form the **root of the penis** (radix penis), which continues as the **body of the penis** (corpus penis) to the **glans of the penis** (glans penis).

The penis is suspended between the thighs on the ventral surface of the trunk with its free extremity pointing towards the umbilicus in all domestic mammals except the cat, where it is directed caudally (Fig. 10-1 to 5 and 25). The organ is constructed of three columns of erectile tissue, which are independent at the root of the penis, but combined throughout the rest of the penis.

The penis is composed of the following divisions and subdivisions:

- **Root of the penis** (radix penis),
  - Crura of the penis (crura penis) formed by two columns of cavernous tissue (corpora cavernosa),
  - Unpaired bulb of the penis (bulbus penis) formed by the spongy body of the penis,
- **Body of the penis** (corpus penis),
  - Cavernous body (corpus cavernosum),
  - Spongy body (corpus spongiosum,
- **Glans of the penis** (glans penis),
  - Os penis, a modification of the cavernous body,
  - Spongy body (corpus spongiosum).

The two dorsal columns of erectile tissue are known as the **crura of the penis** and consist of a core of **cavernous tissue** enclosed by thick connective tissue, the albugineous tunic. The **paired, blood-filled cavernous body** (corpora cavernosa) converge and continue distally into the body of the penis. The cavernous body of each crus remain distinct within the body, where a septum exists between the two.

The **dorsal surface of the body** of the penis is marked by a **shallow groove** (sulcus dorsalis penis), while the ventral surface carries a **deep groove** (sulcus ventralis penis) to accommodate the urethra and its vascular sheet (Fig. 10-30 and 31), the **spongy body.**

The **unpaired spongy body** (corpus spongiosum) provides the third column of erectile tissue and is more delicate than the cavernous body with larger blood spaces, separated by thinner septae. The spongy body originates at the pelvic outlet with the sudden enlargement of the meagre spongy tissue around the pelvic portion of the urethra. The expansion forms the bulb of the penis, formerly called the urethral bulb, a bi-lobed, spongy, blood-filled sac, that lies between the crura close to the ischial arch. The bulb is continuous with the spongy body of the penis surrounding the penile urethra. The spongy body extends beyond the distal end of the cavernous body to form the glans of the penis, which constitutes the apex of the whole organ. The glans of the penis carries the external opening of the urethra (Fig. 10-33) in all domestic mammals except in small ruminants, where a free urethral process prolongs the urethra well beyond the glans (Fig. 10-28).

There are **two different types of penis** in the domestic mammals, which relates to the structure of the cavernous body.

The **fibroelastic type of penis** of ruminants and pigs has small blood spaces divided by substantial amounts of tough fibroelastic tissue and is enclosed by a thick albugineous tunic surrounds the cavernous body as well as the spongy body. In these animals, the non-erect penis exhibits a **sigmoid flexure** (flexura sigmoidea penis) between the thighs. Relatively additional blood is needed in order to make this type of penis become erect and elongation of the penis is mainly achieved by straightening of the sigmoid flexure.

In the other, **musculocavernous type of penis,** the blood spaces are larger and the tunic and intervening septa more delicate and more muscular. This musculocavernous type is

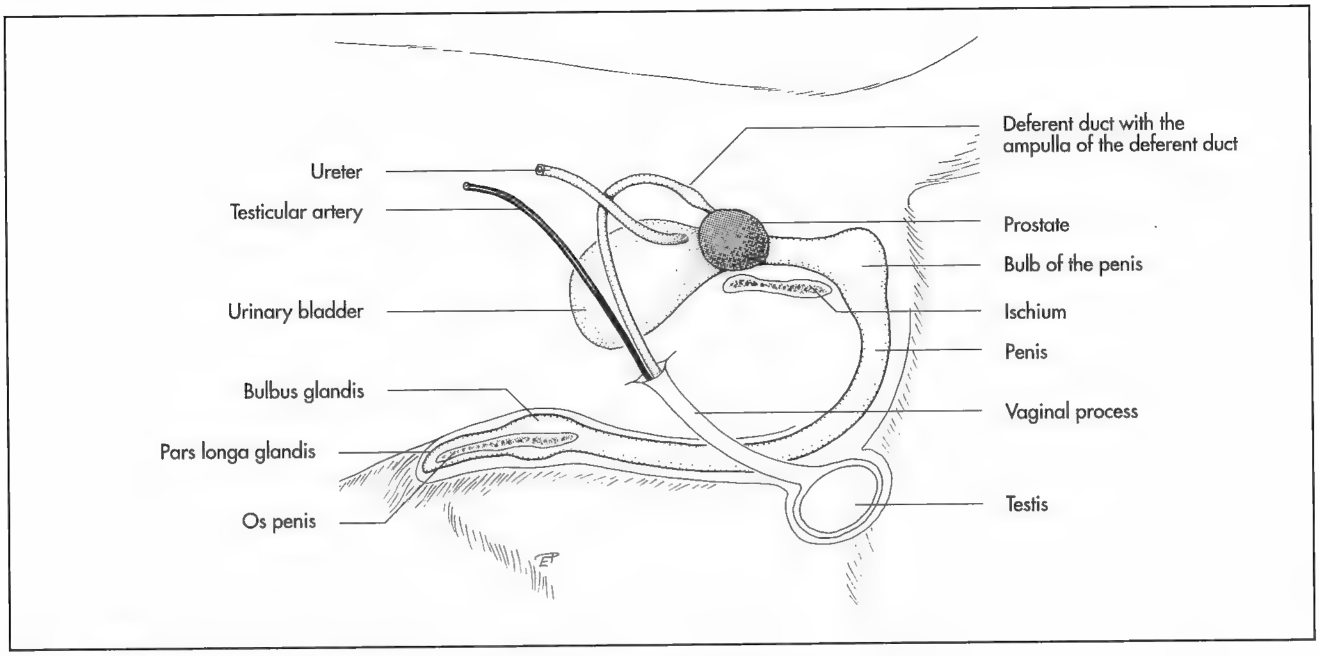

Fig. 10-25. Genital organs and accessory genital glands of the dog, schematic (Dyce et al., 1991).

found in the stallion and in carnivores. A relatively larger volume of blood is required to achieve erection, which is marked by a significant increase in both diameter and length of the penis.

The **glans of the penis** shows species specific modifications (Fig. 10-26 to 29). In the stallion, the glans resembles a mushroom with the **corona** (corona glandis) being the widest part. Towards the body of the penis and behind the corona the glans is constricted to form the **neck of the glans** (collum glandis). The free end of the corona is marked by a central **fossa** (fossa glandis) into which the terminal part of the urethra protrudes (Fig. 10-33). The fossa glandis tends to accumulate smegma, which may cause discomfort, when inspissated.

In the dog, the distal end of the cavernous body is modified to form the **os penis** (Fig. 10-25 and 30), which is grooved ventrally to accommodate the urethra within the spongy body. The partial enclosure of the urethra within the groove of the os penis impedes the passage of urethral calculi, which may become lodged at the proximal end of the bone.

The glans of the penis is rather substantial and is divided into a **long distal part** (pars longa glandis) and an **expanded proximal part,** the **bulbus glandis.** The characteristic form of the two portions of the glans matches the shape of the female vestibular bulbus. Forceful separation of male and female dogs during coitus can cause severe injuries to both animals.

The penis of the cat is unique among domestic mammals being directed caudally in the quiescent state (Fig. 10-1). In the cat the os penis is 5–8mm long and has no ventral groove. The glans carries **keratinised papillae,** which are directed proximally in the non-erect state and radiate in all directions when erect. These papillae regress to in size after castration. During erection, the direction of the penis is reversed with the help of the ligament of the apex of the penis. Obstruction of the urethra by calculi is quite common in the cat.

In the pig the free end of the penis is **twisted around its longitudinal axis,** similar to a corkscrew and is capped by a small glans (Fig. 10-26). Although gross anatomy groups the penis of the pig into the fibroelastic type, there is some histological evidence that support the opinion of some authors that the penis of the pig is of the musculocavernous type.

In the bull, the free extremity of the penis is capped by a small glans, which is **asymmetrical** and **slightly spiralled.** (Fig. 10-29). The urethra ends in a low projection with a slit-like, narrow opening at its tip.

The apex of the penis is very characteristic in small ruminants, in which the urethral process is continued (about 4cm in the sheep and 2.5cm in the goat) beyond the substantial glans. The urethral process contains erectile tissue.

Prepuce (praeputium)

The prepuce, or sheath is a fold of skin, that covers the free end of the penis in the retracted state. It consists of an external lamina and an internal lamina, which are continuous at the **preputial opening** (ostium praeputiale). The equine prepuce is distinctive in having an additional fold that allows for considerable lengthening of the penis during erection.

The **external lamina** is the skin of the outer surface, which continues as the inner sleeve at the preputial ring. It finally forms a visceral layer, which is directly applied to the distal part of the penis (Fig. 10-27). The **internal lamina** has copious amount of lymphoid tissue and modified sebaceous glands that secrete smegma, which facilitates intromission of the penis into the female vagina. The external lamina is marked by a more or less distinct raphe as the continuation of the raphe of the scrotum.

The prepuce can be retracted and protracted by several **striated muscles,** which can be regarded as detachments of

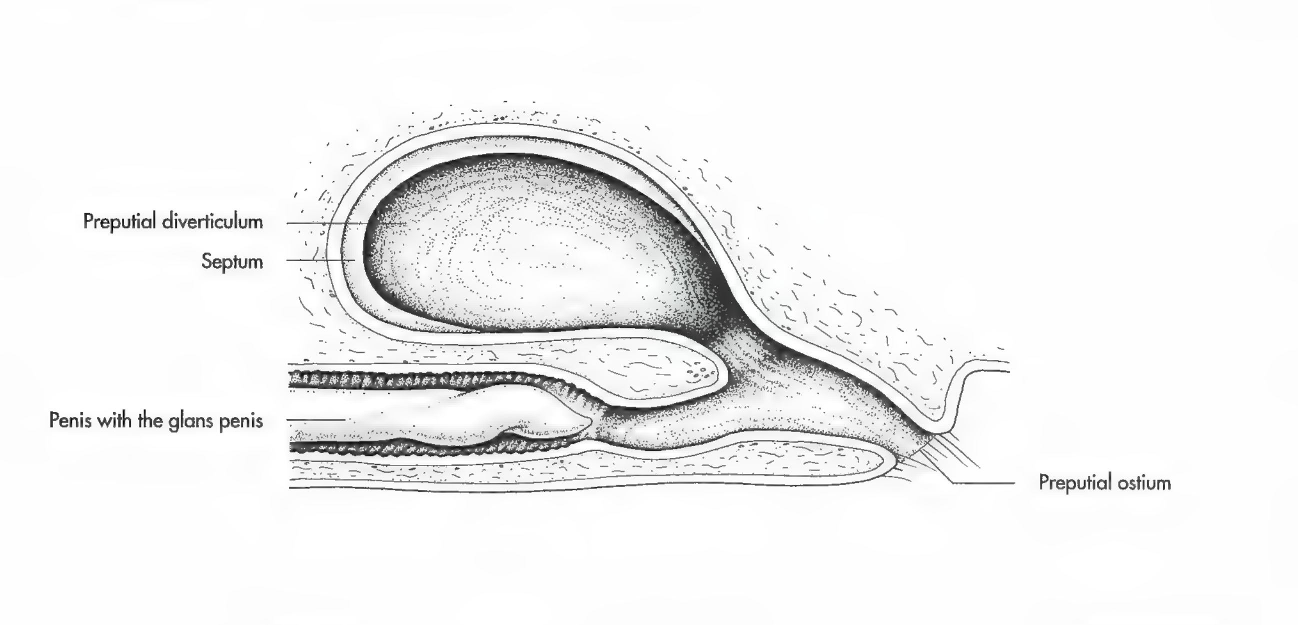

Fig. 10-26. Prepuce and glans of the penis of the boar, schematic.

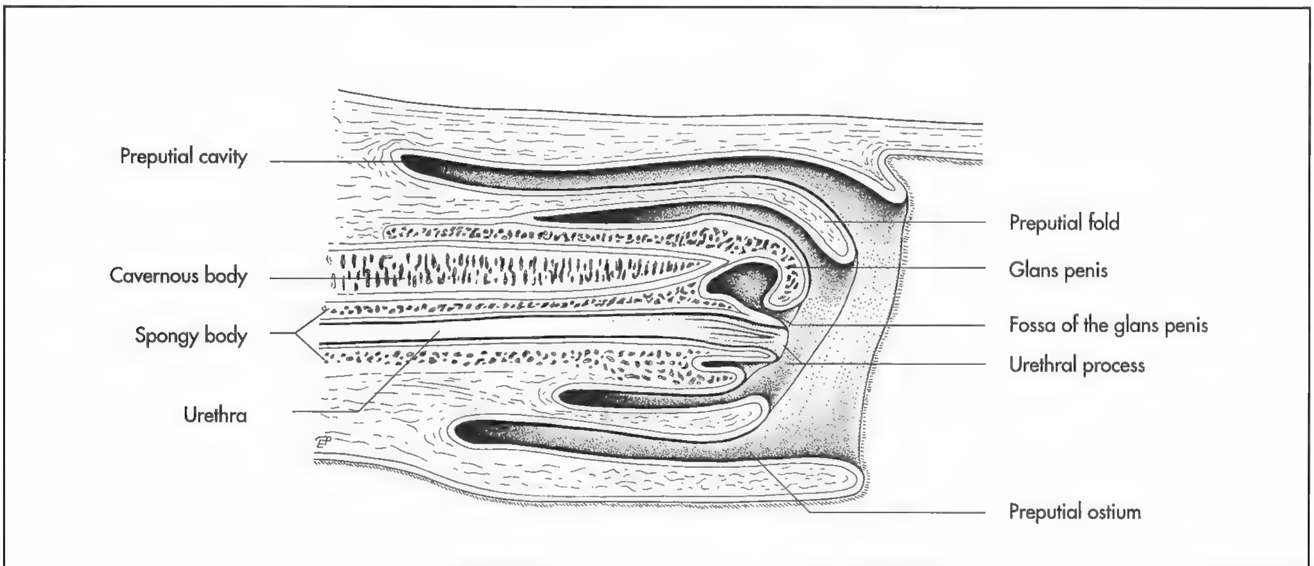

Fig. 10-27. Prepuce and glans of the penis of the stallion, schematic (Schaller, 1992).

the cutaneous trunci muscle. **Caudal preputial muscles** are present in all domestic species, except the horse and serve to retract the prepuce, thus exposing the apex of the penis. The **cranial preputial muscles** that protract the prepuce are found in ruminants only. In the bull and the boar, long hairs surround the entrance to the prepuce. In the boar, the prepuce pouches dorsally to form the preputial diverticulum, this is divided into two compartments by a median septum (Fig. 10-26). It has a capacity of about 135ml and contains foul-smelling fluid made up of cell-debris and urine, which is responsible for their characteristic odour.

Muscles of the penis

The muscles of the penis (Fig. 10-19 to 21) comprise the following:

- Paired ischiocavernous muscle (m. ischiocavernosus),
- Bulbospongious muscle (m. bulbospongiosus),
- Paired retractor penis muscle (m. retractor penis).

The **paired ischiocavernous muscles** are powerful muscles, which arise from the ischial arch and enclose the crura to the

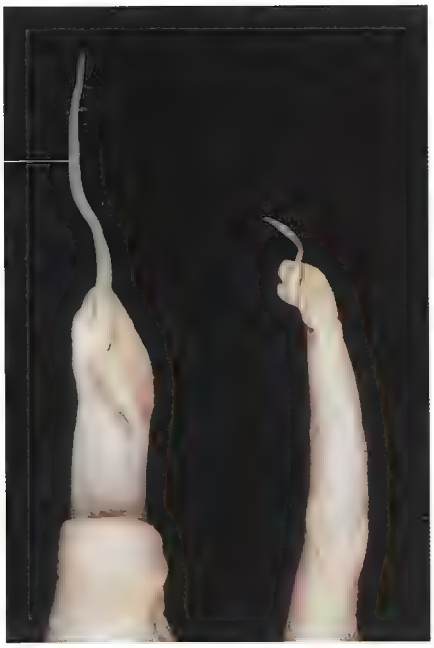

Fig. 10-28. Apex of the penis of a sheep (left) and a goat (right).

Fig. 10-29. Apex of the penis of a bull.

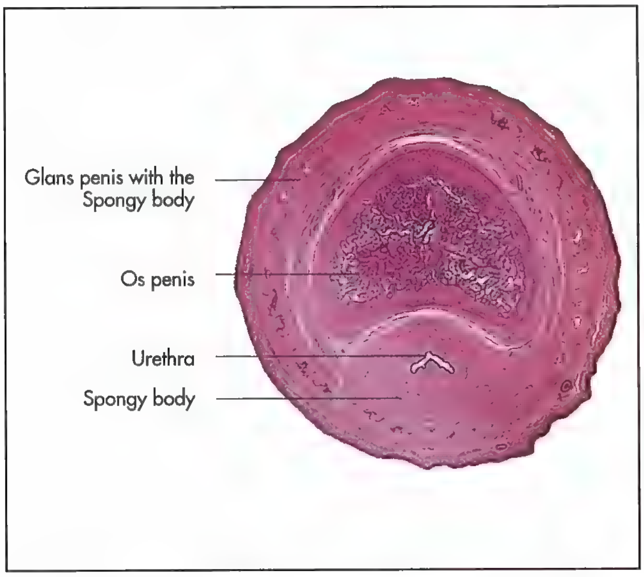

Fig. 10-30. Transverse section of the penis of a dog.

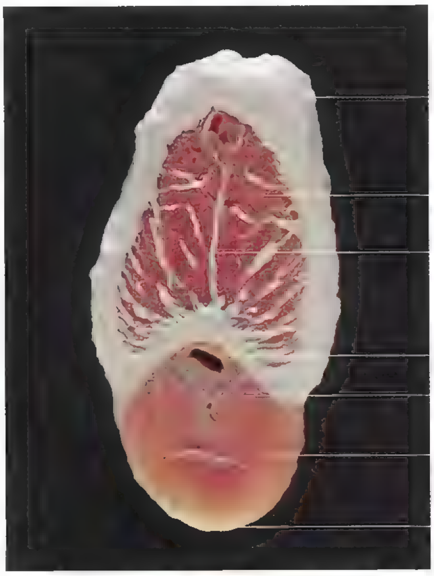

Fig. 10-31. Transverse section of the penis of a stallion.

level of their fusion at the root of the penis. The **bulbospongious muscle** is the extrapelvic continuation of the striated urethralis muscle, which surrounds the pelvic part of the urethra. It extends distally on the surface of the spongy body at a variable distance depending on the type of the penis. In animals with a fibroelastic type of penis, it is limited to the proximal third of the penis, in the stallion it continues to the apex of the penis.

The **retractor penis** is also a paired muscle, which arises from the caudal vertebrae, descends through the perineum around the anus to reach the penis. In species with a sigmoid flexure (ruminants and pig), it attaches to the caudal arch of this flexure, in species with a musculocavernous penis, it follows the bulbospongious muscle to the apex of the penis. It is mainly composed of smooth muscle fibres.

Blood supply, lymphatic drainage and innervation of the urethra and the penis

The urethra, accessory genital glands and the penis are supplied by branches of the **internal pudendal artery.** One branch, the prostatic artery, supplies the genital organs that are located in the pelvic cavity. At the ischial arch the internal pudendal artery

Fig. 10-32. Blood vessels of the apex of the penis of a stallion, corrosion cast.

Fig. 10-33. Apex of the penis of a stallion.

divides into the **artery of the bulb of the penis** supplying the spongy body, the **deep artery of the penis,** supplying the cavernous body and the **dorsal artery of the penis,** which passes along the length of the penis to supply the glans penis.

The **internal pudendal artery** is augmented by branches of the **external pudendal artery** for vascularisation of the apex of the penis, which anastomoses with the dorsal artery of the penis to also vascularise the prepuce. In the stallion, additional anastomoses are formed between the dorsal artery of the penis and the obturator artery.

Lymph vessels from the genital organs located within the pelvic cavity drain into the **medial iliac lymph nodes** and into the **sacral lymph nodes.** The lymph vessels of the penis and prepuce drain into the **superficial inguinal (scrotal) lymph nodes.**

Innervation of the penis is provided by the paired pudendal nerve, which conveys multiple parasympathetic fibres. Numerous nerve endings are found in the glans penis and in the internal lamina of the prepuce.

Erection and Ejaculation

At the beginning of erection, blood flow to the penis increases as the walls of the supplying arteries relax. At the same time venous outflow becomes obstructed at the root of the penis where the veins are compressed against the ischial arch. This has more effect on the cavernous body than on the spongy body, thus the latter fills after the former. The process continues and intensifies after intromission and the pressure within the erectile tissue rises further. After ejaculation the cavernous body empties before the spongy body and the pressure drops rapidly.

In species with a **fibroelastic penis,** little additional blood is required in order to distend the cavernous spaces. Therefore, full erection may be achieved more rapidly. The penis does not increase greatly in size and its protrusion is largely due to the effacement of the sigmoid flexure. In the **musculocavernous type** of penis the cavernous spaces are much larger and more blood needs to be retained for full erection. Thus this process requires more time and there is a much greater increase in length and diameter.

Erection occurs prior to ejaculation. Semen is transported continuously toward the ampulla of the deferent duct by peristaltic movements of the epididymal duct and the deferent duct, which are caused by **smooth muscle cells** within their walls. Secretory activity of the lining of the epididymal duct is regulated by androgens and these have a positive effect on spermatic motility.

Clinical terms related to the male genital system:
Orchitis, orchiectomy, funiculitis, epididymitis, prostatitis, paraprostatic cyst, priapism, phimosis, paraphimosis, cryptorchidism, Sertoli-cell neoplasia, inguinal hernia, testicular torsions.

11 Female genital organs (organa genitalia feminina)

H. E. König and H.-G. Liebich

Analogous to the genital organs of male animals, the female genital organs can be divided into organs that **produce the gametes** and organs that are responsible for **transportation** and **storage of the gametes.** The female genital organs include the **paired ovaries** and **uterine tubes,** the **uterus** and the **vagina.**

The ovaries produce both female gametes and hormones. The paired uterine tubes capture the ova released from the ovaries and convey them to the uterus, where the fertilised ovum is retained. The vagina serves as a copulatory organ and, together with its continuation, the **vestibule,** as a birth canal and as a passage for urinary excretion. (Fig. 11-1).

Ovary (ovarium)

The ovaries originate from the **gonadal primordium,** located in the lumbar region on the medial aspect of the **mesonephros.** These cords of cells incorporate **primordial germ cells,** which have a distant origin in the yolk sac and reach the gonad by migration. Later in the animals development, these cells form cell **clusters,** which differentiate into the **female gametes** and **supporting cells.** A more detailed description can be found in embryology and histology textbooks.

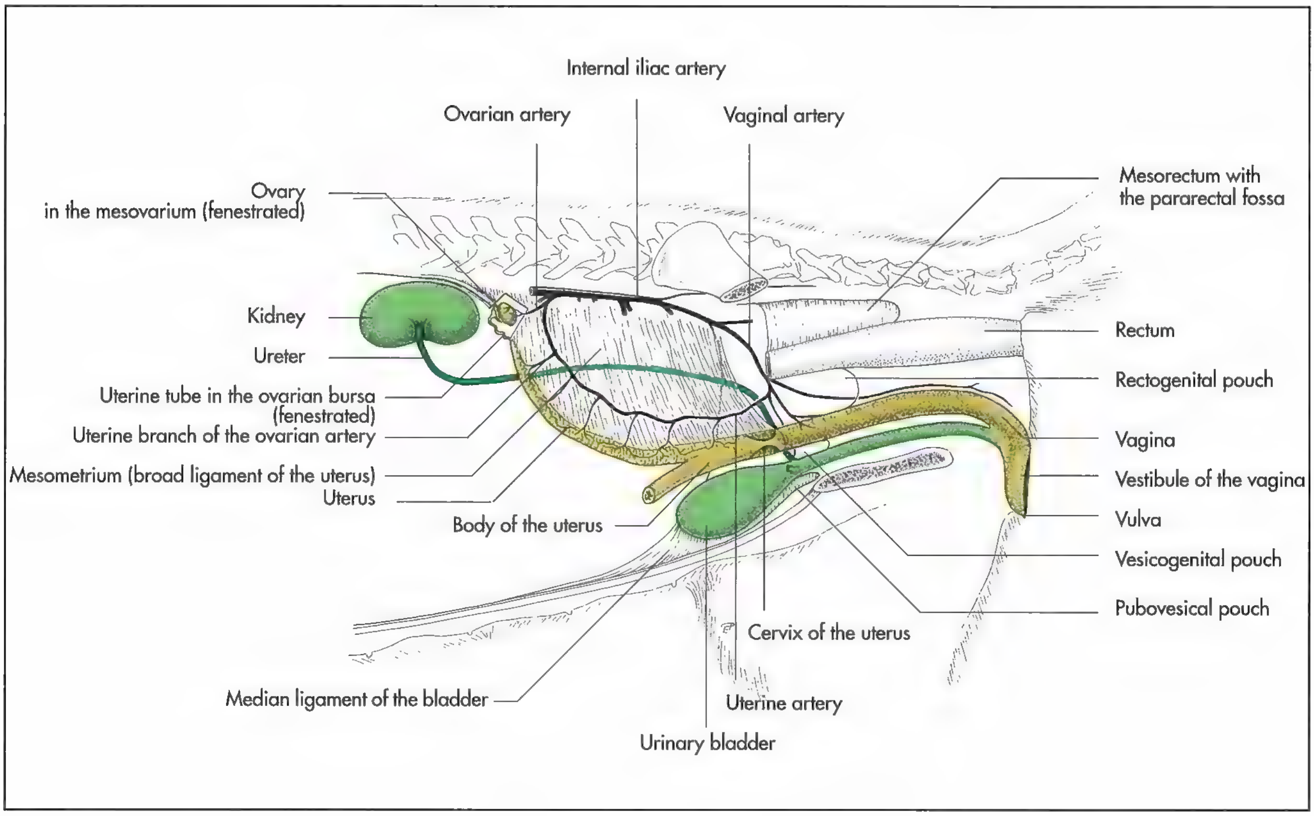

Fig. 11-1. Female genital organs of the dog, schematic.

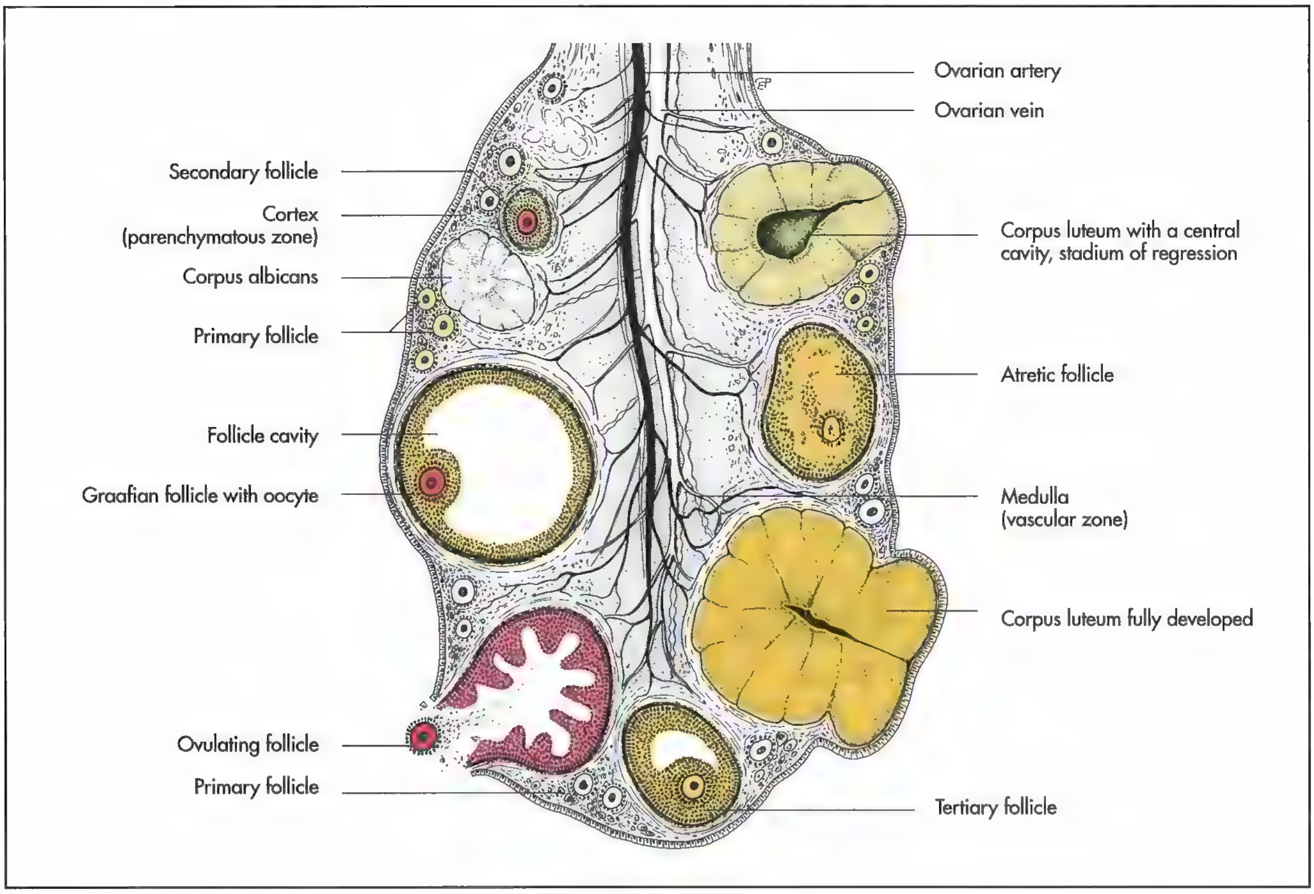

Fig. 11-2. Functional stages of the ovary of the cow, schematic.

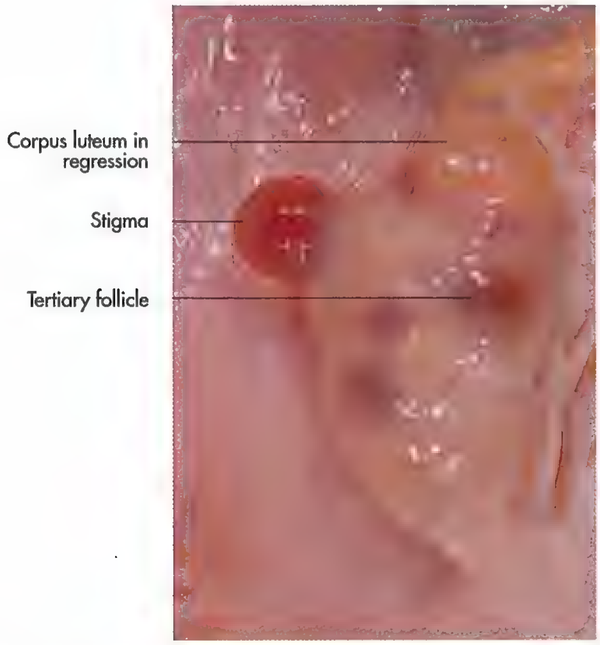

Fig. 11-3. Bovine ovary with a Graafian follicle ready to rupture.

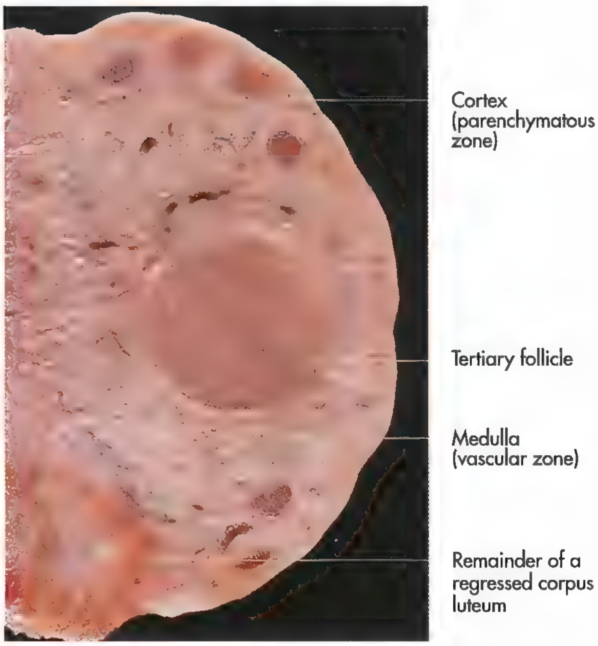

Fig. 11-4. Section of the ovary of a cow.

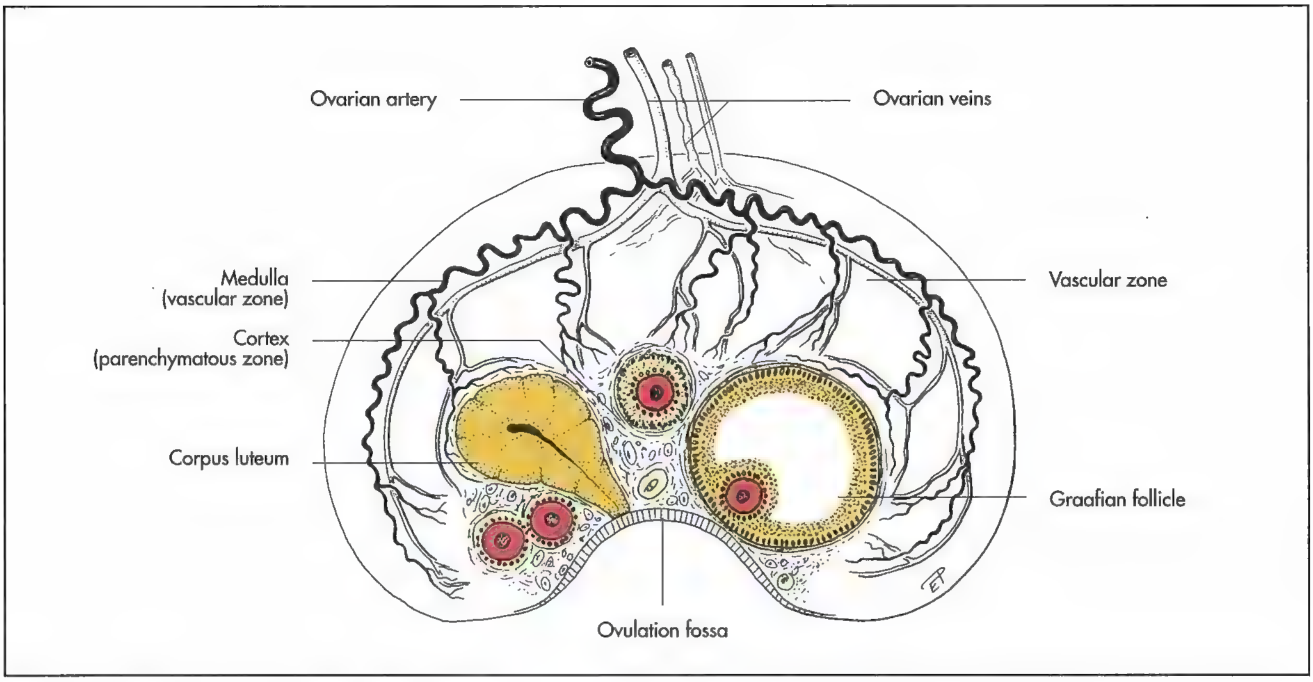

Fig. 11-5. Section of the ovary of the mare, schematic.

Position, form and size of the ovaries

In the dog and cat, the ovaries do not change in location from their place of development, remaining in the **dorsal part of the abdomen** caudal to the kidneys. In the other domestic species the ovaries undergo some degree of migration (descensus ovarii) with the greatest migration occurring in ruminants in which the ovaries come to lie close to the ventral abdominal wall, cranial to the pelvic inlet. In the pig they descend to the middle of the abdomen, in the mare they are located about 8-10 cm ventral to the dorsal wall of the abdomen.
In all domestic species other than the horse, the ovaries are basically ellipsoidal in shape, while their surface is rendered characterised by large follicles and corpora lutea.

The ovaries of the mare have the shape of a kidney and their surface is relatively regular. They are about 4–6 cm in length in the cow, 1.5–2 cm in small ruminants, 8–12 cm in the mare, 1–1.5 cm in the dog and 1.8–1 cm in the cat during active stages of the animals life.

Structure of the ovaries

A section through the ovary of a mature animal, with the exception of the mare shows that it consists of a looser and more **vascular zone** in the centre, the **medulla** (zona medullaris seu vasculosa) and a surrounding denser shell, the **parenchymatous zone** (zona parenchymatosa) (Fig. 11-2 to 4). The parenchymatous zone is bounded by the albugineous tunic directly below the peritoneum.

In the mare, the structure of the ovary is **reversed.** The parenchymatous zone with its follicles form the centre of the organ, which is enclosed within a dense, richly vascularised connective tissue layer that corresponds to the medulla of the other domestic mammals. The parenchymatous zone reaches the surface of the ovary at the **ovulation fossa** (fossa ovarii), a deep indentation at the free margin of the organ, where all mature follicles rupture.
The medulla contains blood vessels, nerves, lymphatics, smooth muscle fibres and connective tissue. The parenchymatous zone contains many follicles and corpora lutea in various stages of development and regression.

Ovarian follicles

In the mature animal, ovarian follicles develop within the parenchymatous zone. Each follicle contains a single ovum. Based on the size of the oocyte and its degree of differentiation, the following stages of development are recognised in ovarian follicles:

- Primordial follicle,
- Primary follicle,
- Secondary follicle,
- Tertiary follicle and
- Graafian follicle.

Primordial follicles are formed by a single-layered follicular epithelium, the **granulosa cells,** which are flat and later differentiate, into **inner thecal cells,** which enclose the oocyte. After transformation of the flat granulosa cells into **cuboidal cells,** the follicle becomes a **primary follicle.** Following further maturation **(secondary follicle),** several layers of granulosa cells are formed around the oocyte with fluid filled gaps within the **granulosa cell mass.** Eventually these become confluent to form a cavity filled with follicular fluid. At this stage the follicle is termed the **tertiary follicle.** At one end of the follicular cavity, there is a **hillock** (cu-

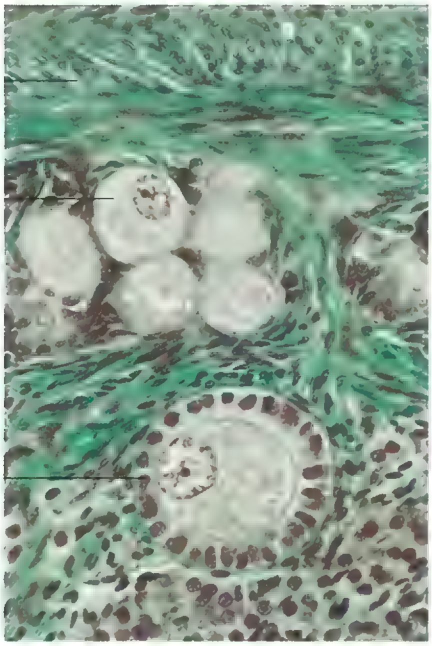

Fig. 11-6. Histological section of the parenchymatous zone of the ovary of a cow.

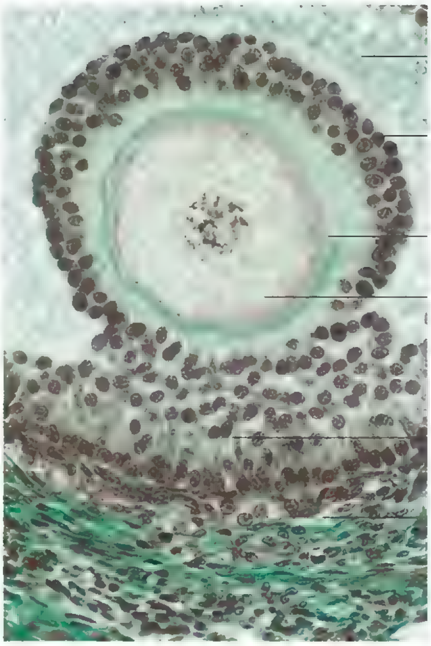

Fig. 11-7. Histological section of a tertiary follicle of a bovine ovary.

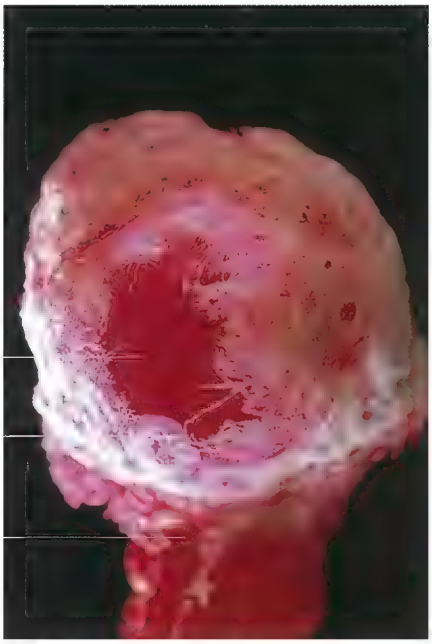

Fig. 11-8. Blood vessels of a bovine ovary prior to ovulation, corrosion cast.

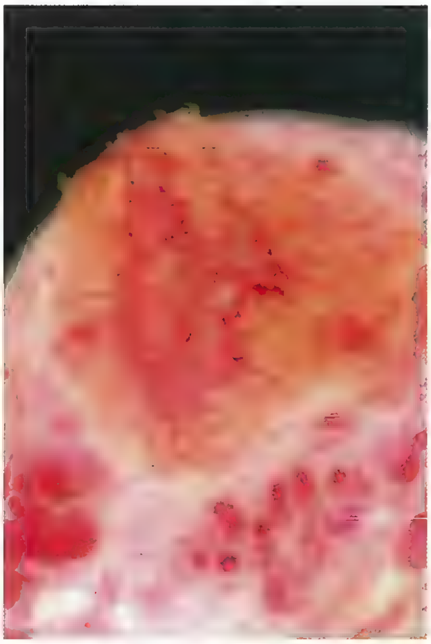

Fig. 11-9. Blood vessels of a bovine ovary after ovulation.

mulus oophorus), which contains the maturing oocyte. In intimate contact with the oocyte is a clear membrane, the **zona pellucida,** which is surrounded by a layer of radially arranged granulosa cells, the **corona radiata** (Fig. 11-7).

On further maturation, the **tertiary follicle** becomes the **Graafian follicle,** which finally ruptures to release the oocyte. In the cow the Graafian follicle measures about 2 cm in diameter (Fig. 11-2 and 3), in the horse 3-6 cm (Fig. 11-5). Complex vascular and endocrine processes prior to ovulation lead to the formation of a preformed **site on the surface of the ovary (stigma),** which finally ruptures under the influence of **Luteinising hormone (LH),** a hormone formed by the pituitary gland. Following ovulation, the oocyte and surrounding cells are flushed from the ovary into the infundibulum of the uterine tube. While ovulation occurs spontaneously in most of the domestic species, it is induced by copulation

Fig. 11-10. Corpus luteum of a cow two days after ovulation.

Fig. 11-11. Blood vessels of a bovine ovary, corrosion cast (König et al., 1987).

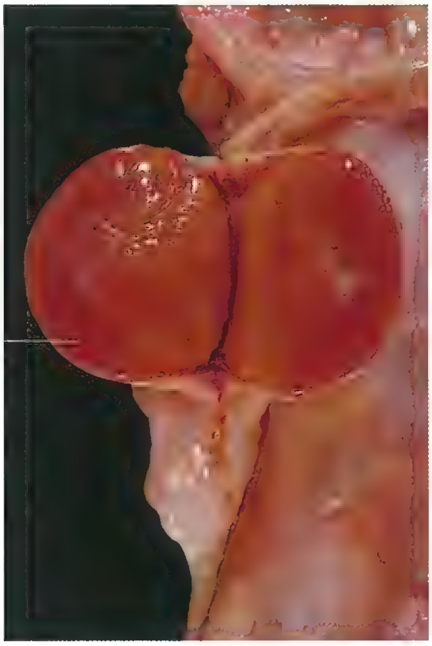

Fig. 11-12. Corpus luteum graviditatis in a pregnant cow, dissected in halves.

Fig. 11-13. Histological section of the corpus luteum of a sheep.

in the cat. Only a **very small number of follicles** and thus oocytes, actually mature to the end stage and become a Graafian follicle, the vast majority undergo regression and finally degenerate (For a more detailed description see histology textbooks.) As the follicle matures, the contained **oocyte** undergoes **meiotic division** and **maturation.** The first phase of **meiotic division** takes place prior to ovulation, except in the dog and horse, in which it this process takes place after ovulation. The second maturation division occurs in the **uterine tube** and requires the **fertilisation of the ovum** by a **penetrating spermatozoon.**

Corpus luteum

After ovulation, the wall of the ruptured follicular cavity folds in. **Slight haemorrhage** occurs at the site of ovulation and fills

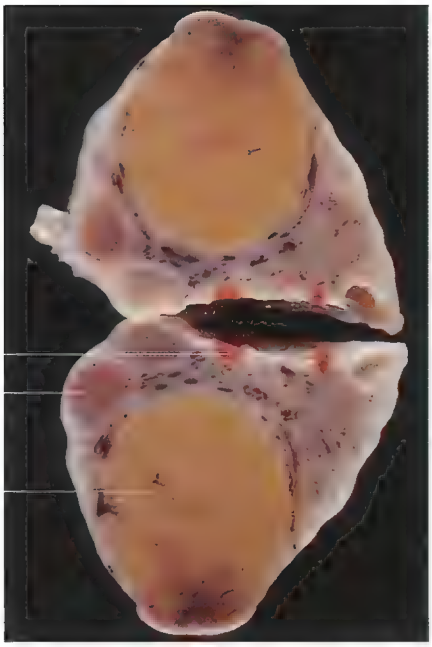

Fig. 11-14. Bovine ovary with mature corpus luteum, dissected in halves.

Fig. 11-15. Bovine ovary with regressing corpus luteum, dissected in halves.

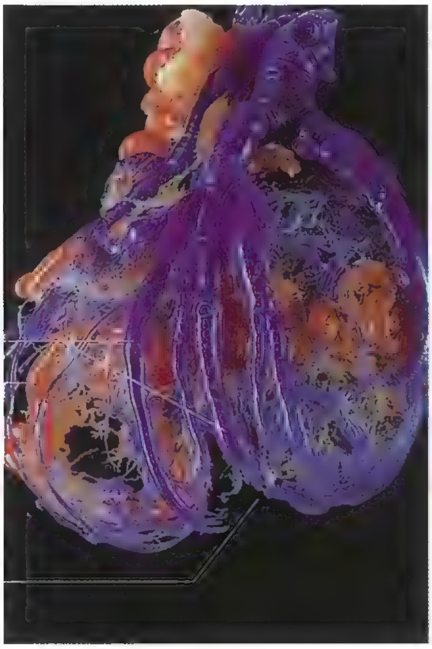

Fig. 11-16. Blood vessels of the ovary of a mare, corrosion cast.

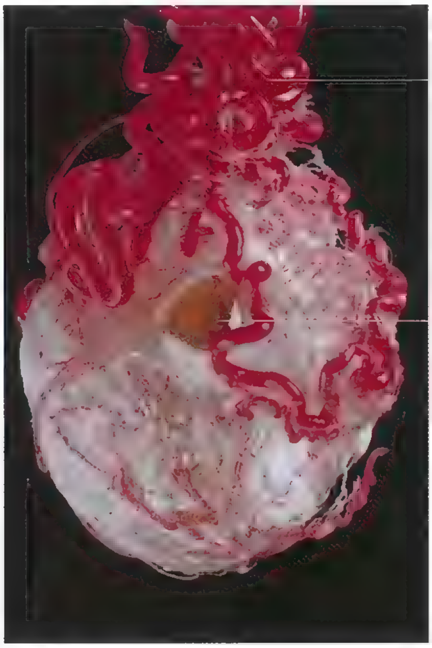

Fig. 11-17. Blood vessels of the ovary of a mare with Graafian follicle of 6 cm diameter, corrosion cast.

the former follicular cavity, which is then referred to as **corpus haemorrhagicum.** As the blood is resorbed, a solid corpus luteum is formed by proliferation of the granulosa and internal thecal cells as well as blood vessels (Fig 11-2 to 5 and 10 to 13).

In the **non-pregnant animal** corpora lutea are transient structures termed **cyclic corpora lutea,** which undergo a phase of proliferation and vascularisation directly after ovulation, followed by a mature stage. The corpora lutea finally regress and degenerates into a connective tissue scar, the **corpus albicans.** The oestrus cycle is regulated by pituitary hormones and disturbance can result in the persistence (corpus luteum persistens) of the corpora lutea or in cyst formation (luteal cyst).

If the **ovum is fertilised,** the corpus luteum, now called **corpus luteum graviditatis,** remains fully developed and active throughout or at least part of the pregnancy. **Corpora lutea** produce **progesterone,** while the cells of the wall of

Fig. 11-18. Ovary and uterine tube of a cow.

Fig. 11-19. Ovary, uterine tube and ovarian bursa of a cow.

mature follicles are the source of oestrogen. Alternation in the levels of progesterone and oestrogen determine changes in the sexual behaviour and in the structure and activity of the genital tract. Higher levels of oestrogen produced by a Graafian follicle causes the animal to show signs of oestrus behaviour, thus signalling that it is ready to mate. Progesterone prepares and maintains the uterus for **implantation of the fertilised ovum.**

In the non-pregnant animal, the uterus produces **prostaglandin (PGF2α),** which causes the corpus luteum to regress. Prostaglandin F2α is transported directly from the ovarian vein into the adjacent ovarian artery through the vessel walls. (A more detailed description can be found in embryology and reproduction physiology textbooks.)

In large animals, **rectal examination** is used to assess the stage of oestrus cycle, which is important information with regards to timing of breeding. In the cow, follicles and corpora lutea may project from any part of the surface and can be relatively easily identified on rectal palpation. In the horse assessment of the ovary is more difficult due to its different structure. While follicles can be identified, corpora lutea cannot be palpated and have to be assessed with the aid of ultrasonography.

Uterine tube (tuba uterina)

The **paired uterine tubes** (also termed oviducts or salpinx) receive and transport the oocytes to the uterus. They also convey the sperm in their ascent. Fertilisation normally occurs within the tubes. Each tube is suspended by the **mesosalpinx** (Fig. 11-19) and connects the peritoneal cavity with the uterine cavity and thus with the external environment (Fig. 11-23 and 24). The **ovarian extremity of the uterine tube,** which receives the oocyte after ovulation, takes the form of a funnel and is termed the **infundibulum.** The free edges of the infundibulum are bordered by numerous diverging processes, called **fimbria,** which contact and sometimes adhere to the surface of the ovary. The inside of the funnel is marked by folds, which converge to border a small opening in the depths of the funnel, the **abdominal ostium.**

The abdominal ostium leads to the **ampulla** (ampulla tubae uterinae), where **fertilisation usually takes place.** The oocyte remains in the ampulla for a few days before it is transported to the apex of the horn of the uterus through the narrower, more convoluted distal part of the tube, the isthmus.

The uterine tube opens into the uterine horn through the **uterine ostium** (ostium uterinum tubae) and marks the site of the uterotubal junction. The junction is gradual in ruminants and pigs but shows an abrupt junction in the horse and in carnivores, in which the uterine ostium is located on top of a papilla, thus forming a barrier against ascending infections.

Mesovarium, mesosalpinx and ovarian bursa

The ovaries and uterine tubes are suspended within the mesovarium and mesosalpinx respectively, which are the cranial parts of the **broad ligament** (ligamentum latum uteri), the common suspension of the female genital tract (Fig. 11-1). Blood vessels and nerves reach the organs within this ligament. In the dog, cat and pig, each ovary has two other ligamentous attachments in addition to the mesovarium. The **suspensory ligament of the ovary** (ligamentum suspensorium ovarii) forms the cranial portion of the free border of the broad ligament (Tab. 11-1). In the cat, this ligament conveys blood vessels, which has to be considered during ovariectomy.

Fig. 11-20. Ovary, uterine tube and uterine horn of a cat.

Fig. 11-21. Ovary, uterine tube and uterine horn of a cat.

The suspensory ligament continues caudally as the **proper ligament of the ovary** (ligamentum ovarii proprium), which attaches to the apex of the uterine horn. The mesosalpinx extends beyond the uterine tube, its has a curtain-like free border (Fig. 11-19 to 21 and 24).

The mesovarium, mesosalpinx and the proper ligament of the ovary enclose a small peritoneal cavity, the **ovarian bursa** (bursa ovarica), which surrounds the ovary (Fig. 11-19).

In the mare, the ovary is too large to be located within the bursa, in ruminants and pigs the ovarian bursa covers the ovary like a cape. In the cat, the bursa surrounds the ovary but has a wide communication with the abdominal cavity. In the dog, the bursa encloses the ovary completely, as well as a variable amount of fat. Communication with the peritoneal cavity is restricted to a narrow slit-like opening (foramen bursae ovaricae).

Uterus (metra, hystera)

Like the salpinx and the vagina, the uterus (Greek hystera or metra) develops from the paramesonephric ducts of the embryo. The caudal parts of the ducts fuse to an extent that varies with the species and accounts for the different forms of the uterus in adult animals. In some species, including many rodents, fusion of the ducts is limited to the vagina, thus the uterus consists of paired tubes, which open separately into the vagina **(uterus duplex).** In contrast, in human beings and most primates fusion is much more extensive and only the uterine tubes remain paired **(uterus simplex).** The uterus of the domestic mammals belongs are intermediate in form **(uterus bicornis)** and comprise (Fig. 11-22 to 25):

- Single median cervix (cervix uteri),
- Single median body (corpus uteri),
- Paired horns (cornua uteri).

The anatomy of the uterus changes considerably with age and physiological activity. This following description deals with the uterus of the mature, parous, but non-pregnant animal.

In carnivores, the uterus lies mainly **dorsal to the small intestines.** It consists of a short cervix and body from which **two long slender horns** diverge to reach the ovaries just **caudal to the kidneys.** An internal partition, which is not discernible externally, projects into the body of the uterus separating the horns. A similar partition is also present in the sow, in which the septum is limited to the cranial part of the uterine body and in the cow, in which the septum extends almost as far as the cervix.

The uterus of the pig consists of a **long cervix,** a short body and **remarkably long horns,** which resemble loops of small intestine. They are suspended by extensive broad ligaments and both the horns and the ovaries are so mobile that that they cannot be assigned exact positions within the abdominal cavity.

In ruminants, each horn is **coiled ventrally on itself** with the first convexity facing dorsocranially. The **tips of the horns** reach **beyond the pecten of the pubis** into the abdominal cavity. Externally, the uterine body appears to be very long, but in fact, most of the so-called body is the caudal part of the horns, which are enclosed in a common serosal and muscular sheet. Where the horns do diverge, the superficial tissues bridge the space between them, forming the **intercornual ligaments,** which can be conveniently used to fix the uterus during rectal examination.

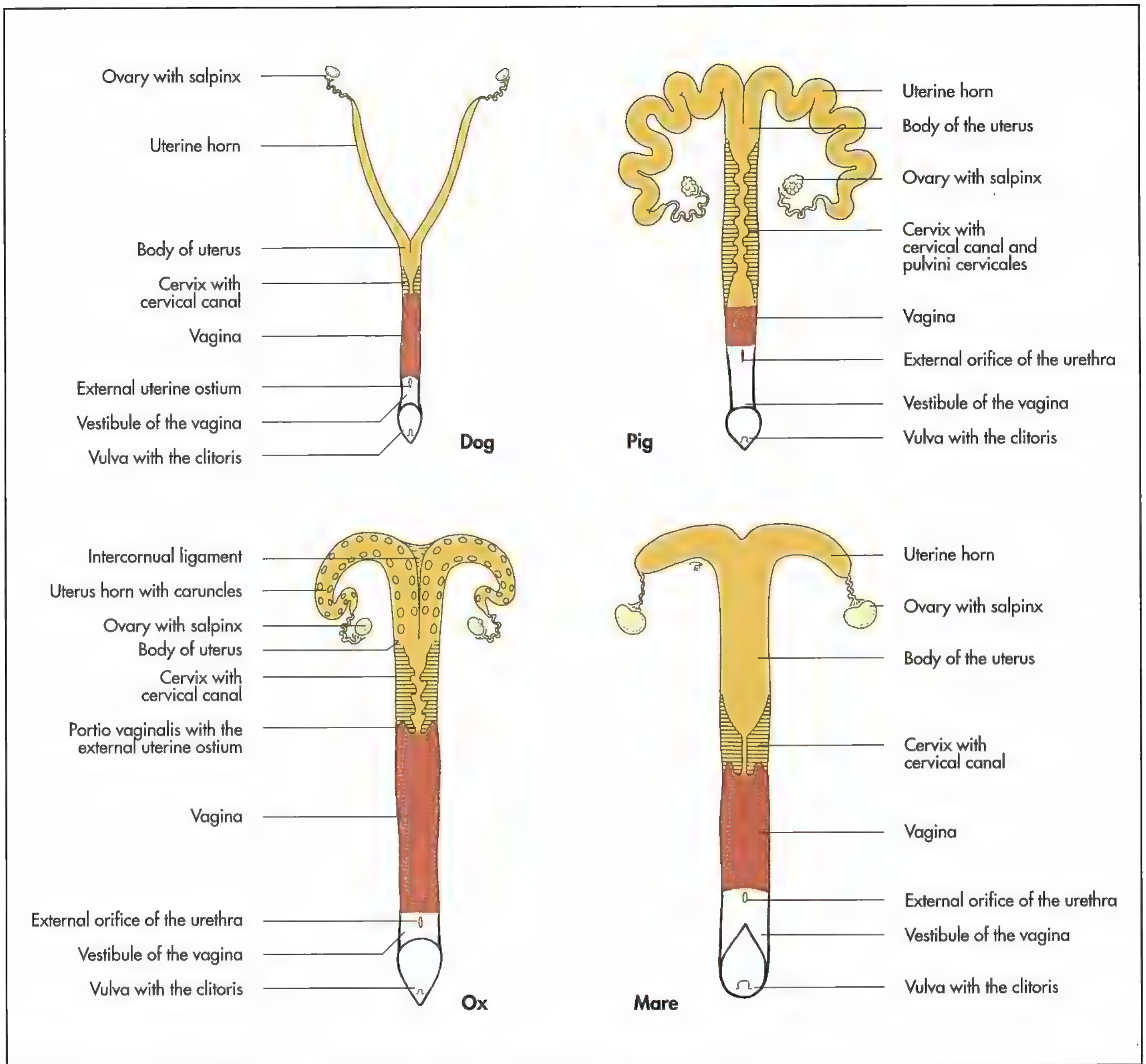

Fig. 11-22. Female genital organs of the domestic mammals, schematic (Najbrt and Kaman, 1982).

The uterus of the mare has a **large body** and **two divergent horns,** which are usually raised towards the roof of the abdomen **above the mass of intestines** (Fig. 11-22). The cervix is comparatively small and can be easily palpated rectally.

The thick-walled **cervix of the uterus** (cervix uteri) can be palpated transrectally and forms a sphincter controlling access to the uterus. The lumen of the cervix is the **cervical canal** (canalis cervicis), which is formed by and often almost occluded by **mucosal folds.** These folds are arranged longitudinally in the mare, cat and dog. In the cow the lumen is obstructed by **circular folds** (plicae circulares), in the pig, these folds form **rows of prominences** (pulvini cervicales), which interdigitate into the lumen of the canal, resulting in its occlusion (Fig. 11-22).

The cervical canal opens cranially into the body of the uterus at the **internal uterine ostium** (ostium uteri internum) and caudally into the vagina at the **external uterine ostium** (ostium uteri externum) (Fig. 11-25). The most caudal part of the cervix (portio vaginalis) usually projects into the vaginal lumen in the cow and mare, where it is surrounded by an annular space (fornix vaginae). In the pig and dog, the cervical canal simply widens to continue into the vagina. In the cat, the external ostium of the uterus opens on a small hillock projecting into the vagina.

The **cervical mucosa** produces a **mucous secretion,** which forms a mucous plug that helps closing the cervical canal, which is easily expelled during oestrus and parturition.

Fig. 11-23. Uterine tube of a cow.

Fig. 11-24. Uterus of a sow after injection of the arteries (on the left, in red) and lymph vessels (on the right, in black) (courtesy of PD Dr. J. Maierl, Munich).

Structure of the uterine wall

A section through the wall of the uterus shows it to consist of three layers. These are, from the inside to the outside:

- Mucosal layer (endometrium),
- Muscular layer (myometrium),
- Serosal layer (perimetrium).

The Greek names of the different layers form the derivation of many clinical terms related to the uterus, such derivatives are for example endometritis or pyometra. The **endometrium** lines the lumen of the uterus. Its thickness varies depending on the stage of the oestrus cycle. Numerous tubular glands (glandulae uterinae) open on the surface (Fig. 11-29). In ruminants the surface is marked by numerous permanent elevations (80–120 in the cow), the **uterine caruncles,** the at-

Fig. 11-25. Genital organs of a sow, dorsal apect, partially opened on midline (courtesy of PD Dr. J. Maierl, Munich).

tachment sites of the embryonic membranes (cotyledons) during pregnancy. While they are low, smooth-surfaced elevations in the non-pregnant cow, they become converted into large, sessile swellings with a pitted surface in the pregnant state. Each uterine caruncle and its foetal counterpart, the cotyledon constitutes a single unit known as placentome. Underlying the endometrium is a two-layered muscular layer, the **myometrium** (Fig. 11-29). The myometrium consists of an **external longitudinal** and a thicker **internal circular layer** separated by a highly vascular stratum of connective tissue.

The uterus is covered by a serous membrane **(perimetrium)** which is continuous with the broad ligament. Numerous blood vessels and nerve fibres are located at the **parametrium,** the site where the double layer of the broad ligament separates to enclose the uterus. The tissues of the uterine coats, especially the external muscle layer extend into the ligaments at the parametrium (Fig. 11-29).

Vagina

The vagina constitutes the cranial part of the female copulatory organ. It extends from the external ostium of the uterus to the **entrance of the urethra** (ostium urethrae externum) (Fig. 11-22, 25, 33 and 36). Thus, it is part of only the reproductive tract. A transverse fold cranial to the opening of the urethra represents the remains of the hymen present in human beings. Although variable, it is generally more prominent in the horse and pig than in the other domestic species.

The relatively long and thin-walled vagina is located in a median position within the pelvic cavity between the rectum dorsally and the bladder ventrally. It is mostly **retroperitoneal,** although its cranial parts are covered by peritoneum. Incision of the dorsal wall of this part of the vagina provides a relatively convenient means of access to the peritoneal cavity of large animals. This approach can be used for removal of the ovaries **(ovariectomy)** in the mare. A ventral incision is not possible due to the presence of an extensive plexus of veins.

In the cow and the mare, the protruding cervix restricts the lumen of the cranial part of the vagina to a ring-like space, known as the fornix. In the dog, the vaginal epithelium responds to changes in hormonal levels in a more pronounced way than in the other domestic species and smears taken from the vagina provide evidence of the stage within the cycle.

Fig. 11-26. Uterus horn of a pregnant cat (courtesy of PD Dr. S. Reese, Munich).

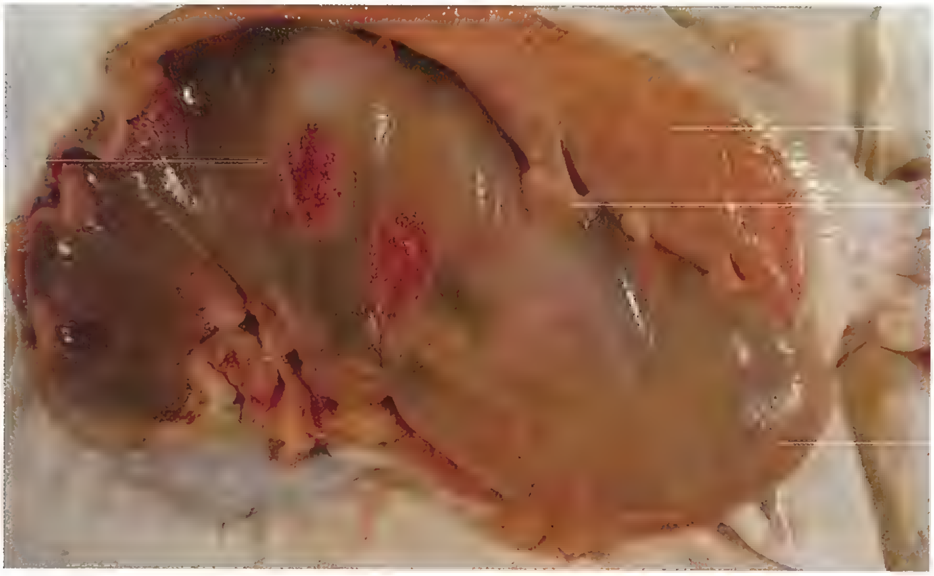

Fig. 11-27. Uterus of a pregnant cow with foetus (third month of gestation).

Vestibule of the vagina (vestibulum vaginae)

The vestibule constitutes the caudal part of the **copulatory organ.** It extends from the external urethral opening to the external vulva and combines reproductive and urinary functions (Fig. 11-22, 25 and 36).

In the cow and sow, the urethra forms a ventral evagination, the suburethral diverticulum, which opens together with the urethra into the vagina. This arrangement can complicate catheterisation of the urinary bladder. In the dog, the urethra opens on a small elevation flanked by two grooves, which should not be mistaken with the fossa of the clitoris during catheterisation. In the cow, the openings of the vestigial mesonephric ducts may be visible on each side of the external urethral opening.

The **vestibule** is shorter than the vagina and lies mostly behind the ischial arch, which permits it to slope ventrally to its opening at the vulva. The resulting inflection of the axis of the genital passage must be taken into consideration when introducing a vaginal speculum or other instruments.

The wall of the vestibule contains **vestibular glands,** the secretion of which keeps the mucosa of the vestibule moist

Fig. 11-28. Placentome of a cow, formed by the separated fetal cotyledone and the maternal caruncle.

Fig. 11-29. Histological section of the uterus of a sheep (Liebich, 2004).

and facilitates coitus and parturition. At oestrus, the odour of the secretion has a sexually stimulating effect upon the male animal. In the bitch the glands are small, but numerous and the duct openings are arranged in linear series. Some **minor vestibular glands** (glandulae vestibulares minores) are also present in the pig, sheep, cow and mare. In the cow and ewe a **large glandular mass,** which drains by a single duct, is present on each side of the vestibule.

Darker patches of the lateral walls betray the position of the **vestibular bulbs,** a concentration of veins forming erectile tissue, regarded as the homologue of the bulb of the penis.

Vulva

The vulva is formed by **two labia** that meet at dorsal and ventral commissures surrounding the **vertical vulvar** opening. The dorsal commissure is rounded and the ventral one pointed (Fig. 11-36), except in the mare in which this pattern is reversed (Fig. 11-37). The clitoris lies within the ventral commissure, the female homologue of the penis.

Analogous with the penis it can be divided into two parts, a **body** (corpus) and a **glans** (glans clitoridis). The clitoris lies within a **fossa** (fossa clitoridis) largely covered by a mucosal fold, the female equivalent of the prepuce. It becomes very

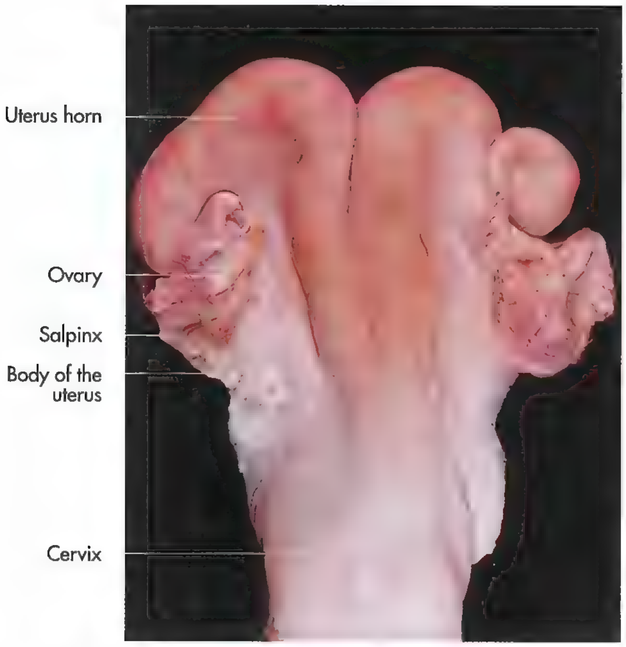

Fig. 11-30. Uterus, ovaries and uterine tubes of a cow (courtesy of PD Dr. J. Maierl, Munich).

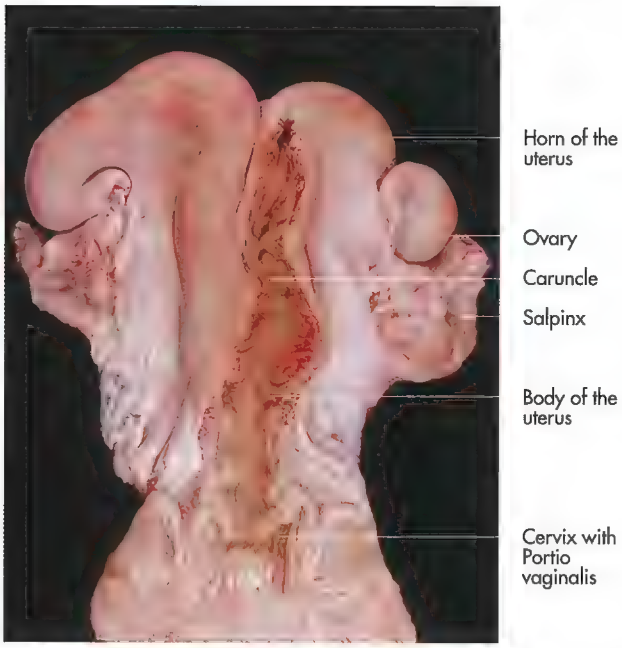

Fig. 11-31. Uterus, ovaries and uterine tubes of a cow (uterus opened) (courtesy of PD Dr. J. Maierl, Munich).

prominent in the mare during oestrus, when exposed by "winking" movements of the labia. In the mare several **clitoral sinuses** (sinus clitoridis) invade the glans, which may harbour the organisms responsible for contagious equine metritis (CEM) (Fig. 11-37).

Ligaments (adnexa)

The principal attachment of the female genital organs is provided by the paired double folds of peritoneum, the left and right **broad ligaments of the uterus** (ligamenta latum uteri). The broad ligaments are bilateral sheets that suspend the ovaries, uterine tubes and the uterus from the abdominal roof and the pelvic walls. Based upon the organ it suspends, the broad ligament can be divided into three parts, the mesovarium, the mesosalpinx and the mesometrium (Fig. 11-23 and 24). Unlike most peritoneal folds, the serosal membranes of the broad ligament are separated by considerable amounts of tissue, mainly smooth muscle from the longitudinal layer of the myometrium (Fig. 11-32). This arrangement enables the broad ligaments to play an active role in the support of the uterus, which is of particular importance in large animals.

The **mesovarium** is the cranial part of the broad ligament that attaches the ovary to the dorsolateral region of the abdominal wall. The mesovarium contains the ovarian artery and vein. The mesosalpinx extends laterally from the mesovarium, thus dividing the mesovarium in a proximal and a distal part. The proximal mesovarium extends from the body wall to the mesosalpinx, while the distal mesovarium extends from the mesosalpinx to the ovary.

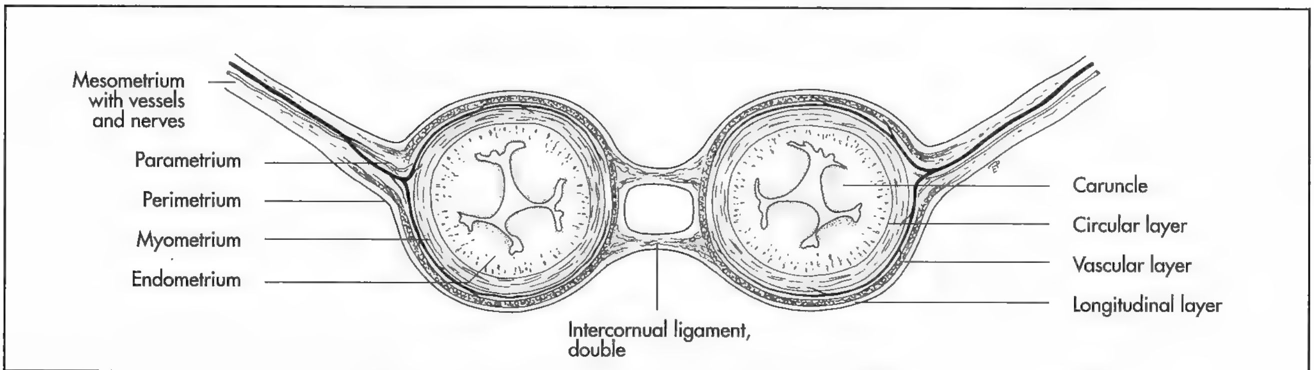

Fig. 11-32. Uterine horns of a cow, dissected at the level of the intercornual ligament, schematic.

Fig. 11-33. Vagina and uterine cervix of a sow, partially opened on midline (courtesy of PD Dr. J. Maierl, Munich).

The mesosalpinx and mesovarium enclose a pouch, the **ovarian bursa** (bursa ovarica), into which the ovary projects. The ovarian bursa is very variable in size and is unable to hold the ovary in the mare, but encloses the whole ovary in carnivores.

The largest part of the broad ligament is the **mesometrium,** which attaches to the uterus and the cranial part of the vagina. The two serosal membranes of the mesometrium are widely separated where they attach to the cervix and the vagina, therefore their lateral surfaces are retroserosal. At the base of the uterine horns, the serous membrane pass from one horn to the other, thus bridging the space between them and forming the intercornual ligament. In the cow, there are dorsal and ventral intercornual ligaments, that form a small pocket, open cranially, which facilitates manual fixation of the uterus during rectal palpation.

In addition to the ligamentous attachments described, the female genital tract has other ligaments, the **suspensory ligament of the ovary,** the **proper ligament of the ovary** and

Tab. 11-1. Comparison of analog mesentery and ligaments of the female ovary and male testis.

Mesentery female	 male	Ligaments female	 male
Proximal mesovarium	Proximal mesorchium	Cranial ligament of the ovary (Suspensory ligament of the ovary)	Cranial ligament of the testis (Suspensory ligament of the testis)
Distal mesovarium	Distal mesorchium	Caudal ligament of the ovary (Inguinal ligament of the ovary)	Caudal ligament of the testis (Inguinal ligament of the testis)
Mesosalpinx	Mesepididymidis	Proper ligament of the ovary	Proper ligament of the testis
Ovarian bursa	Testicular bursa	Round ligament of the uterus	Ligament of the tail of the epidymis

Fig. 11-34. Uterine cervix of a cow, opened.

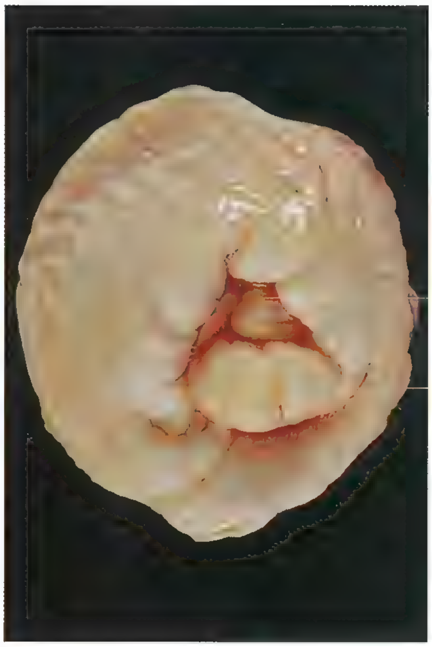

Fig. 11-35. Uterine cervix of a cow.

Fig. 11-36. Vagina and vulva of a sow, opened midline (courtesy of PD Dr. J. Maierl, Munich).

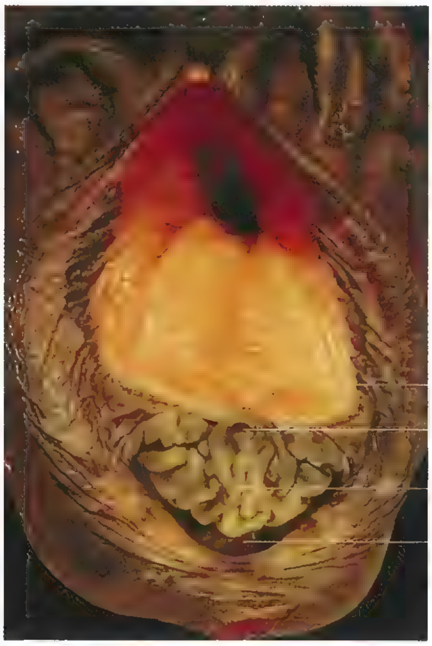

Fig. 11-37. Vulva of a mare.

the **round ligament of the uterus.** The **cranial boundary of the broad ligament** is formed by the **suspensory ligament of the ovary** (ligamentum suspensorium ovarii), which extends between the ovary and the last ribs. The suspensory ligament is continued after the ovary with the caudal **proper ligament of the ovary** (ligamentum ovarii proprium), which in turn attaches to the cranial end of the uterine horn. There it is continuous with the round ligament of the uterus (ligamentum teres uteri), a fibrous-muscular cord, which extends caudally toward the inguinal canal within the free margin of a fold of peritoneum that detaches from the lateral aspect of the mesometrium. In the dog the round ligament does not end at the inner inguinal ring, but passes through the **inguinal canal** (canalis inguinalis) to be enclosed by the **vaginal process** (processus vaginalis peritonei) before it ends near the vulva. The bitch is unique amongst the domestic mammals in possessing

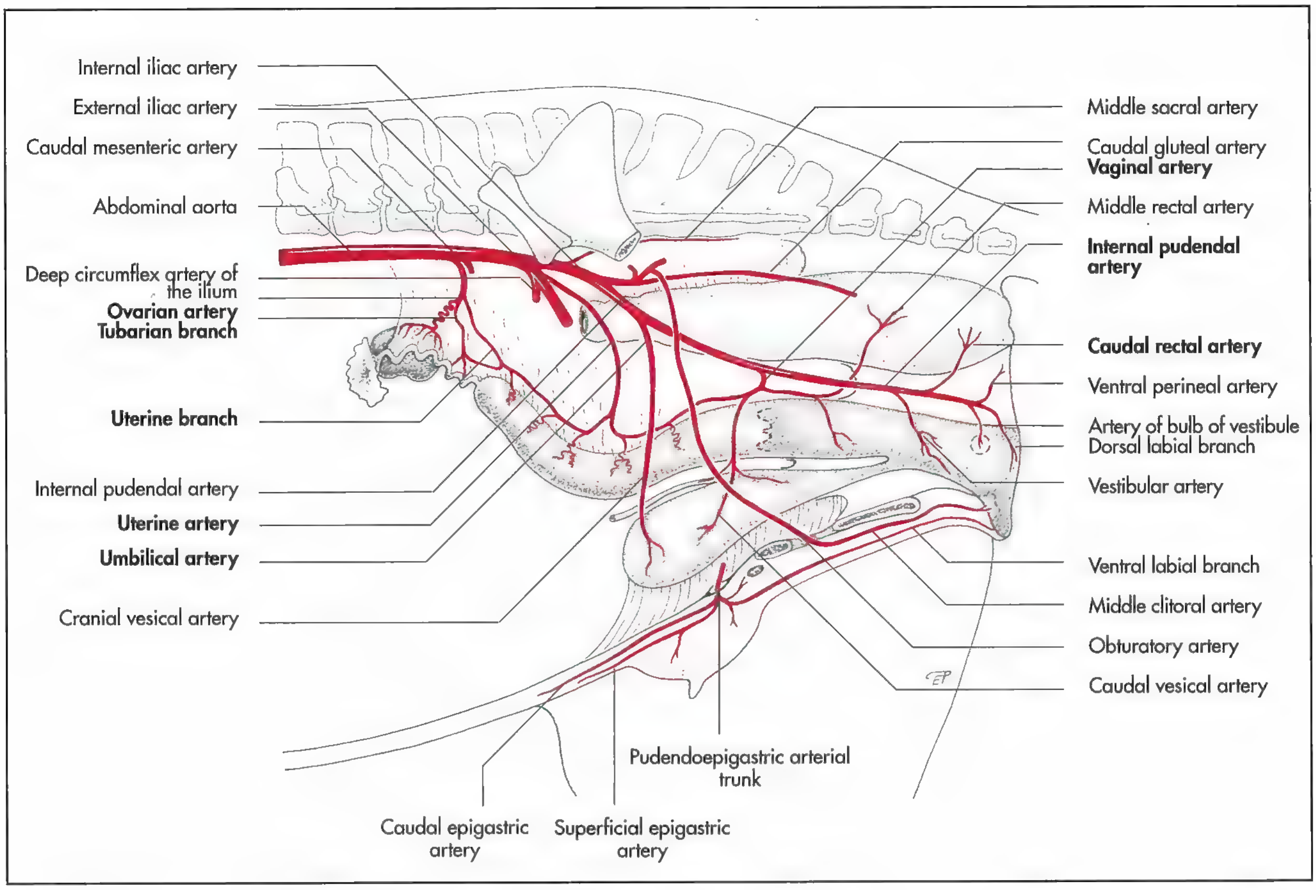

Fig. 11-38. Blood vessels of the genital organs of the mare (paramedian section), schematic.

a vaginal process. This predisposes them to inguinal hernias, a condition, which is restricted to the male of other species. In older bitches a considerable amount of fat is deposited within the vaginal process, this renders it easily palpable, but should not be mistaken for a pathological mass.

The suspensory system and ligamentous attachment of the genital tract is listed in table 11-1, comparing the homologue structures of male and female animals.

Muscles

The **muscles** and **fasciae** associated with the female reproductive tract constitute parts of the **pelvic outlet.** A musculofascial partition, which is divided into the pelvic diaphragm dorsally, which closes the pelvic outlet around the anus and a ventral part, the urogenital diaphragm that closes the pelvic outlet around the vestibule. The **muscles of the vestibule** and the **vulva** comprise the following striated muscles: the **constrictor of the vestibule,** the **constrictor of the vulva** and the **ischiocavernous muscle.** The region between the ventral aspect of the root of the tail and the vulva (or the scrotum) is termed the perineal region. The muscles and fascia, which interlace between the vulva and the anus, is referred to as the perineal body. However in practice the perineal body is often referred to as **"the perineum".** During complicated parturition, the perineal region may become lacerated.

Blood supply, lymphatic drainage and innervation

Blood supply to the female genital organs is provided by four paired arteries (Fig. 11-38):

- Ovarian artery (a. ovarica),
- Uterine artery (a. uterina),
- Vaginal artery (a. vaginalis) and
- Internal pudendal artery (a. pudenda interna).

After dividing from the aorta, the **ovarian artery** follows a convoluted course to the ovary. It supplies the **ovary** (ramus ovaricus) and detaches branches to the uterine tube and to the tip of the **uterine horn** (ramus uterinus). The uterine branch anastomoses with the uterine artery within the broad ligament.

The rest of the female genital tract is supplied by the uterine and vaginal arteries, which are branches of the internal iliac artery and by the continuation of the vaginal arteries, the internal pudendal artery. The uterine artery passes to the uterus within the broad ligament. It detaches a series of branches to the body and horn of the uterus, the most cranial of which anastomose with the uterine branch of the ovarian artery, and the most caudal anastomose with the vaginal artery.

In the dog and cat, the uterine artery is a branch of the **vaginal artery.** The major blood supply to the uterus is provided by the uterine branch of the ovarian artery. In the cat, the ovarian artery detaches an additional branch, which runs cranially and anastomoses with the artery of the adrenal gland. In the cow the uterine artery can be palpated rectally against the shaft of the ilium, a characteristic vibration (fremitus or thrill) may be appreciated from the fifth month of gestation onwards.

In the mare the uterine artery is a branch of the external iliac artery.

The caudal parts of the female genital tract are supplied by branches of the internal pudendal and vaginal arteries; the pattern of branching varies in different animals.

The **veins** are generally satellites to the arteries, but do not correspond to each other in relative importance. The **ovarian vein** (v. ovarica) is much larger and the **uterine vein** (v. uterina) much smaller than their accompanying arteries. The ovarian vein drains most of the uterus and runs together with the ovarian vein in a common soft tissue sheath. The adjacent vessel walls are considerably thinner than the others and facilitate transmural transportation of Prostaglandin F2α from the vein into the artery. Prostaglandin F2α is produced in the non-pregnant uterus and causes regression of the corpus luteum (luteolysis). The **vaginal vein** (v. vaginalis) vascularises an extensive plexus in the walls of the vagina and vestibule.

The **lymphatics** of the female genital tract drain primarily into the **medial iliac lymph nodes** and to the **lumbar aortic lymph nodes.** In the mare, an **uterine lymph node** may be present in the broad ligament.

Innervation of the female genital organs is provided by the **autonomic nervous system.** The ovaries receive sympathetic fibres from the intermesenteric and the caudal mesenteric plexus and parasympathetic fibres from the vagus.
The rest of the female genital tract receives parasympathetic and sympathetic innervation via the **pelvic plexus** (plexus pelvinus).

Clinical terms related to the urinary system:
Ovariectomy, hysterectomy, ovariohysterectomy, salpingitis, metritis, endometritis, myometritis, perimetritis, parametritis, pyometra, vaginitis.

12 Organs of the cardiovascular system (systema cardiovasculare)

H. E. König, J. Ruberte and H.-G. Liebich

The cardiovascular system comprises the heart, the blood vessels and the lymphatic vessels. The heart constitutes the muscular pump of the cardiovascular system. The blood vessels, consisting of the arteries, capillaries and veins form a continuous system in which the blood circulates through the body.

Blood delivers **oxygen** and **other molecules** necessary for the normal **cell metabolism,** to the tissues and in turn, transports cell products from the tissues to the liver, the kidneys and the lung for the metabolism and **excretion.** The blood vessels and the chambers of the heart form a single cavity, through which the blood circulates continuously, due to the pumping action of the heart. In the domestic mammals other than the cat, blood volume is about 6–8% of the animals bodyweight, while in the cat, it represents only 4% of bodyweight.

Circulation time, the time it takes for a blood cell to be transported from one jugular vein around the body, largely depends on the size of the animal, but also on individual factors mediated by the neuroendocrine system. In large animals, it takes approximately 30 seconds and only seven seconds in the cat.

The **blood vessels** include the **arteries,** which transport blood away from the heart, whilst **veins** return blood to the heart. When the arteries branch and divide, they form **arterioles,** with a smaller diameter, which lead into the **capillaries,** which have the smallest diameter, and allow passage of cells and nutrients into the tissues. Capillaries empty into **venules,** which in turn become the veins, and return blood to the heart.

The **blood vessels** are arranged as **two circuits of blood flow,** following a figure of eight pattern with the heart in the centre (Fig. 12-1). The **larger, systemic circulation** conveys **oxygenated blood** from the heart to all the organs of the body and transports **deoxygenated blood** back to the heart. The **smaller, pulmonary circulation** conveys **deoxygenated** blood from the heart to the exchange tissue of the lungs, where it is **oxygenated** before it is returned to the heart.

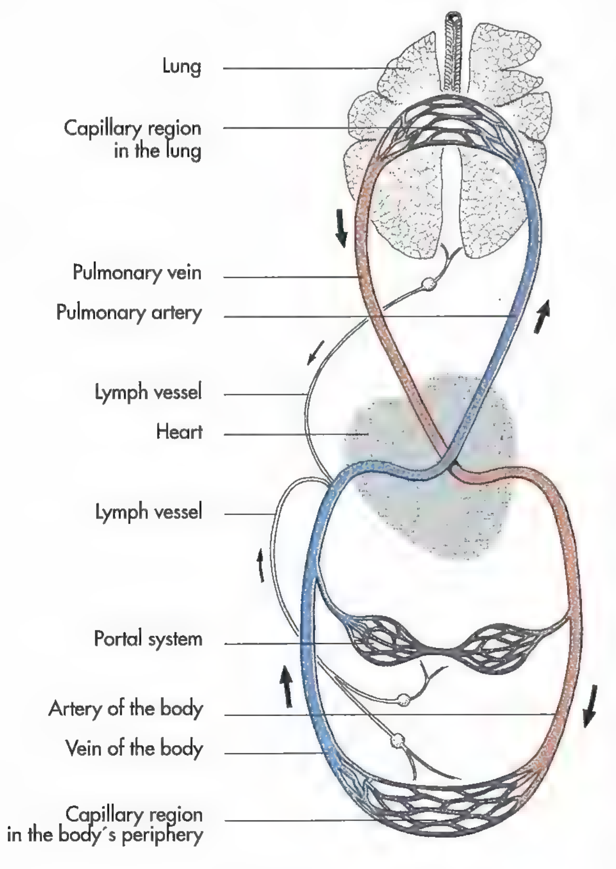

Fig. 12-1. Systemic and pulmonary circulation, schematic (Leonhardt 1991).

Although blood is circulated throughout the animals life, it is useful to consider the path of an individual erythrocyte to facilitate an understanding of flow. Starting with the **left atrium,** oxygenated blood passes both passively and by atrial contraction into the **left ventricle.** The muscular contraction of the left ventricle discharges blood into the **aorta.** From the aorta arise arteries that branch into arterioles and finally run into the capillary beds of the different organs through which the blood circulates.

From the **capillary beds** the deoxygenated blood is collected by **smaller venules,** which become **veins** and eventually **major veins (cranial** and **caudal vena cava),** which empty the blood into the **right atrium of the heart.** The veins of the pelvic limbs and the caudal part of the trunk discharge into the **caudal vena cava,** the veins of the head, thoracic limbs and the cranial half of the trunk are collected by the **cranial vena cava.** Venous blood from the **unpaired or-**

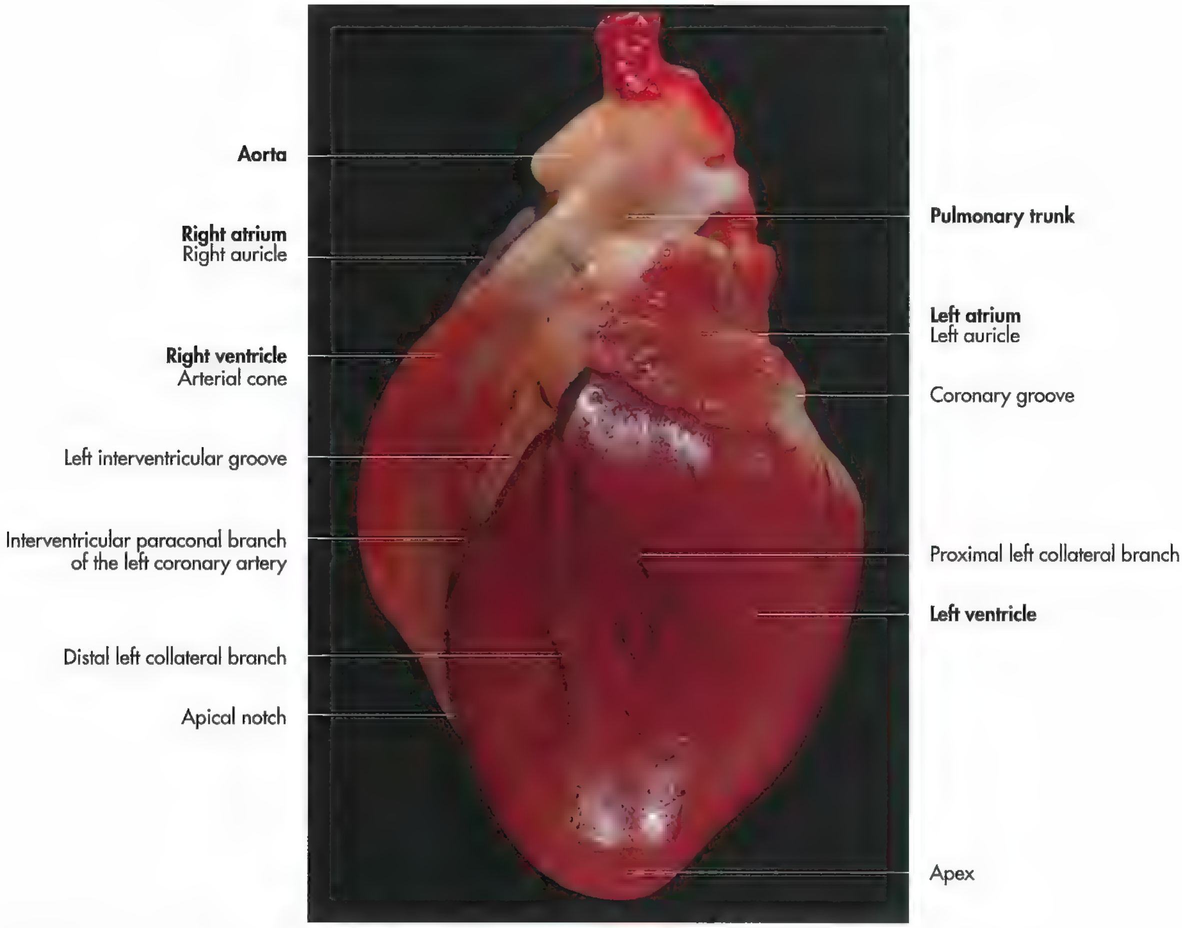

Fig. 12-2. Heart of a cat, auricular surface (König, 1992).

gans within the abdomen passes through the **portal vein,** and liver, before reaching the **right atrium** with the **caudal vena cava.**

From the **right atrium** the blood passes into the **right ventricle** (passively and by atrial contraction) and from there into the **pulmonary trunk** and the **pulmonary arteries,** which convey the deoxygenated blood to the pulmonary alveoli, where gaseous exchange takes place. The **pulmonary veins** transport the oxygenated blood back to the left atrium.

Lymph vessels form a **drainage system,** which returns an important fraction of the tissue fluid from the interstitium to the circulating blood. Lymphatic drainage starts with the **blind-ending lymphatic capillaries,** which form extensive plexuses, spreading through most tissues. These capillaries collect interstitial fluid, including large molecules, such as proteins, which are unable to enter the less permeable blood vessels. Larger lymphatic vessels take origin from these plexus and finally converge upon a few **large trunks,** which empty into the **major veins** within the thorax. The second component of the lymphatic system comprises a variety of widely scattered aggregations of **lymphoid tissue** through which the lymph passes. The lymphatic system is described in detail in chapter 13 "The immune system and lymphatic organs (organa lymphopoetica)".

Heart (cor)

The heart is the **central organ** of the cardiovascular system. It is mainly composed of **heart muscle** (myocardium), which forms a sac, divided into **four chambers: right atrium, left atrium, right ventricle, left ventricle.** The heart is enclosed within the **pericardium** forming part of the mediastinum, the partition that separates the two pleural cavities.

Pericardium

The pericardium, or heart sac, is the fibroserous covering of the heart. It is essentially a deeply invaginated sac, with its lumen, the **pericardial cavity** (cavum pericardii), being reduced to a capillary cleft. This cleft contains a small amount of **serous fluid** (liquor pericardii) which facilitates movement of the heart against the pericardium.

Inflammation of the pericardium results in an increase of pericardial fluid and thickness of the sac. In these cases, the pericardial fluid can be visualised ultrasonographically as an anechoic region.

The pericardium can be divided into an **outer fibrous** and an **inner serous part.** The serous part can be further subdivided into a **parietal** and a **visceral layer:**

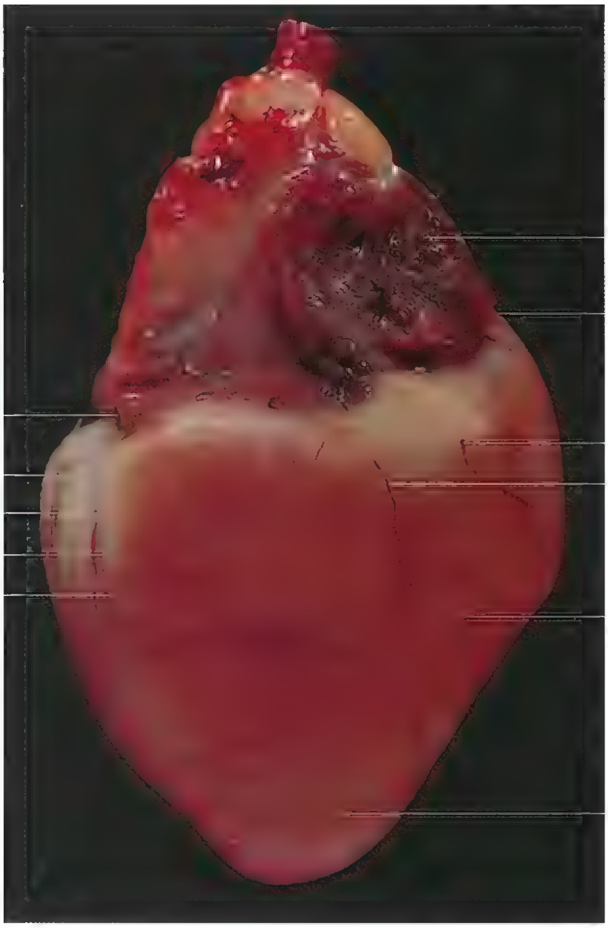

Fig. 12-3. Heart of a cat, atrial surface (König, 1992).

- **Serous pericardium** (pericardium serosum),
  - Visceral layer (lamina visceralis, epicardium),
  - Parietal layer (lamina parietalis) and
- **Fibrous pericardium** (pericardium fibrosum).

The **visceral layer of the pericardium** is firmly attached to the heart wall, forming the **epicardium.** It covers the myocardium, the coronary vessels and fat on the surface of the heart. The visceral and parietal layers of the pericardium are continuous with each other, forming a complicated reflection that passes over the atria and the roots of the great vessels. The roots of the large blood vessels are also enclosed in epicardium, as part of the pericardial cavity curves transversely across the base of the heart. This is the **transverse sinus of the pericardium** (sinus transversus pericardii), a U-shaped cleft between the right and left side of the pericardial cavity.

The **oblique sinus of the pericardium** (sinus obliquus pericardii) is an invagination formed by the reflection of the two layers of the serous pericardium between the large veins.

The **parietal layer of the serous pericardium** is firmly fused to the fibrous pericardium, which is composed of interlacing collagenous fibres. The base of the **fibrous pericardium** is continuous with the great arteries and veins that leave and enter the heart, uniting with the adventitia of these vessels. Ventrally it continues into the following ligaments:

- Sternopericardiac ligament (ligamentum sternopericardiacum),
- Phrenopericardiac ligament ligamentum phrenicopericardiacum).

The **sternopericardiac ligament** attaches the fibrous pericardium to the sternum. The **phrenopericardiac ligament** is only present in the dog, and joins the fibrous pericardium to the diaphragm. The greater part of the outside of the fibrous pericardium is covered by the mediastinal pleura, which is described in detail in chapter 6. The phrenic nerve passes between the mediastinal pleura and the pericardium.

The pericardium is only able to accommodate a small degree of distension during the rhythmic pulsation of the cardiac cycle. Rapid accumulation of fluid within the pericardial cavity exerts pressure on the heart and impairs cardiac function (cardiac tamponade). Long term changes either in heart size, seen with training and disease, or a slow build up of effusion in the pericardial cavity, are better tolerated and may result in an enlargement of the pericardium.

Fig. 12-4. Heart of a horse, auricular surface (courtesy of PD Dr. J. Maierl, Munich).

Position and size of the heart

The heart is located **within the mediastinum** with the larger part (60%) lying to the **left of the median plane.** It extends between the third and sixth (seventh in the cat and dog) rib. The heart base is roughly located on a horizontal plane drawn through the middle of the thorax. Most of the surface of the heart is covered **by the lung,** although the heart can easily be heard on auscultation and felt through the thoracic wall (apex beat).

The **cardiac notch** of the lungs allows the heart to come in closer contact with the **lateral thoracic wall,** separated only by the pericardium, the mediastinum and the pleura. In juvenile individuals its cranial aspect is adjacent to the thymus. Caudally the heart extends as far as the **diaphragm.** Variations in position and size occur among species, breeds and individuals, according to age, condition and the presence of disease. As a rough guide, the heart provides about 0.75% of the body weight. On radiographs the size of the heart size can be compared to intercostal spaces, or vertebral length and several systems for documenting cardiac size have been developed.

Shape and surface topography of the heart

The heart resembles a cone with its **base** (basis cordis) lying dorsal and the **apex** (apex cordis) ventral, close to the sternum. In the dog and cat the longitudinal axis of the heart is tilted in varying degrees (about 45 degrees in the dog), so that the base faces craniodorsally and the apex caudoventrally. Though generally conical, it is laterally compressed, especially towards the apex, conforming with the thorax.

The base of the heart is the **hilus of the organ,** through which the great veins enter and the great arteries leave. The heart has a **right** (facies atrialis) and a **left** (facies auricularis) **lateral surface,** which meet cranially in the **right ventricular border** (margo cranialis dexter) and caudally in the **left ventricular border** (margo ventricularis sinister).

The **auricles of the atria** (auricula cordis, atrial appendages) are visible on the left side, surrounding the root of the aorta and the pulmonary trunk, while the main parts of the atria, and the large veins are located on the right side.

The divisions of the internal structure of the heart are visible as grooves on the surface of the heart. The right or atrial surface of the heart is marked by the right **interventricular groove** (sulcus interventricularis dexter seu subsinosus), which extends from the coronary groove to the apex of the

Fig. 12-5. Heart of a horse, atrial surface (courtesy of PD Dr. J. Maierl, Munich).

heart (Fig. 12-3 and 5). The **left interventricular groove** (sulcus interventricularis sinister seu paraconalis) runs over the left surface of the heart from the coronary groove to the distal third of the cranial margin (Fig. 12-2 and 4). The **coronary groove** (sulcus coronarius) marks the separation of the atria and ventricles. It contains large amounts of fat, which surrounds the coronary blood vessels. The coronary groove also marks the separation of the thinner muscle of the atria from the much thicker muscle of the ventricle by a **fibrous skeleton (also called cardiac skeleton).** The cardiac skeleton is formed by the rings that encircle the four **heart orifices** (anuli fibrosi). The skeleton contains islands of fibrocartilage in which nodules of bones (ossa cordis) may develop.

Although these bones occur most commonly in cattle, they are not confined to this species and may be found in other domestic mammals. The fibrous skeleton is perforated close to the entrance of the coronary sinus to allow passage to the atrioventricular bundle, the special neuromuscular tissue, which conducts the impulse, necessary for the organised contraction of the heart

Compartments of the heart

The heart is divided internally by a longitudinal **interventricular septum** (septum interventriculare) (Fig. 12-6) into **left** and **right sides.** These in turn are incompletely divided by a transverse septum into the blood receiving **atria** (atrium cordis) and the blood-pumping **ventricles** (ventriculus cordis) (Fig. 12-2 to 7).

Atria of the heart (atria cordis)

Right atrium (atrium dextrum)

The right atrium forms the right, dorsocranial part of the base of the heart. It receives the blood from the cranial and caudal vena cava and the **coronary sinus** (sinus coronarius), which collects the venous blood from most of the heart itself. It is divided into a main part, the **sinus of the venae cavae** (sinus venarum cavarum) and a blind-ended part, the **right auricle** (auricula dextra). It is separated from the left atrium by the **interatrial septum** (septum interatriale).

The **intervenous tubercle** (tuberculum intervenosum), a transverse ridge of tissue between the openings of the two vena cavae, protrudes into the interior of the right atrium and di-

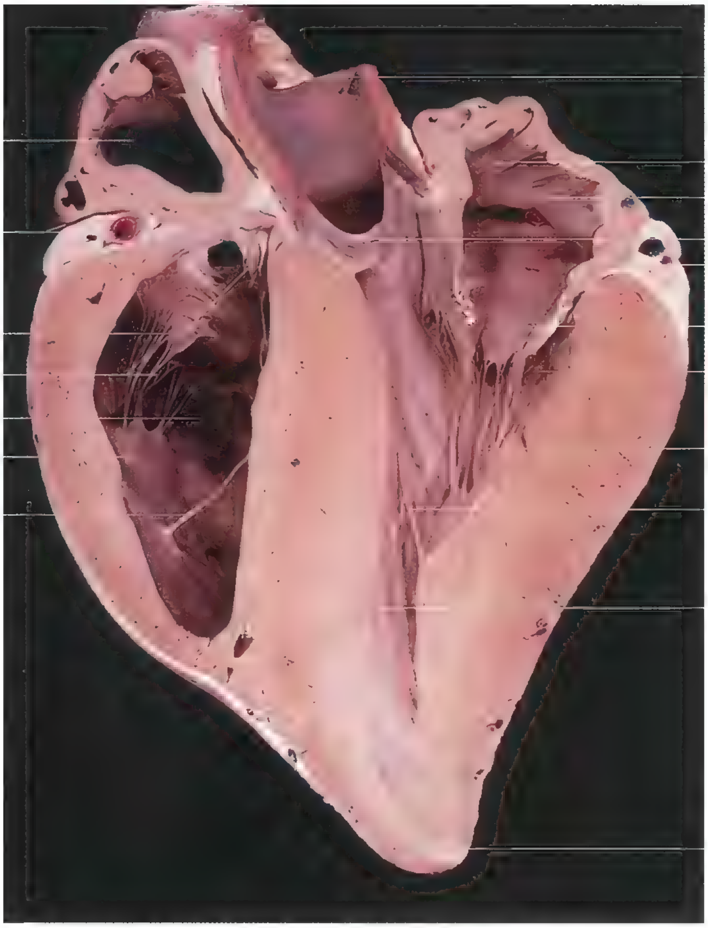

Fig. 12-6. Interior of a heart of a horse, longitudinal section (courtesy of PD Dr. J. Maierl, Munich).

rects the inflow of blood through the **atrioventricular opening** (ostium atrioventriculare dextrum). Just caudal to this tubercle, on the interatrial septum is a depressed area, the oval fossa, which is the remnant of the foramen ovale of foetal development. The internal surface of the wall of the right auricle is strengthened by interlacing **muscular bands** (musculi pectinati), forming irregular ridges on the surface.

Left atrium (atrium sinistrum)

The left atrium forms the left, dorsocaudal part of the **base of the heart.** It receives the oxygenated blood from the pulmonary veins. It is similar to the right atrium in shape and structure (Fig. 12-6 and 7). It opens into the left ventricle by the left atrioventricular opening. Several openings mark the entrance of the pulmonary veins into the left atrium.

Ventricles of the heart (ventriculi cordis)

The ventricles constitute the **majority of the mass** of the heart. They are separated from the atria by a transverse, incomplete septum, which is indicated on the surface by the coronary groove (Fig. 12-2 to 6).

Right ventricle (ventriculus dexter)

The right ventricle is crescent shaped in cross section and moulded on the surface of the conical-shaped left ventricle. It does not extend as far the apex of the heart, which is usually formed by the left ventricle alone (Fig. 12-6 and 7). The right ventricle receives the **deoxygenated blood** from the **right atrium** and pumps it through the conus arteriosus into the **pulmonary trunk** (truncus pulmonalis), which conveys the blood to the lung.

The **conus arteriosus** is the funnel-shaped part of the right ventricle, which is separated from the main chamber by the **supraventricular crest** (crista supraventricularis) and is embraced by the right auricle externally. The supraventricular crest is a blunt, obliquely positioned ridge of muscle that projects ventrally between the origin of the conus arteriosus and the atrioventricular opening.

Located in the **right atrioventricular** opening is the **right atrioventricular** or **tricuspid valve** (valva atrioventricularis dextra seu tricuspidalis) (Fig. 12-6 and 7). It is composed of three cusps that attach peripherally to the fibrous rings of the **"cardiac skeleton"** encircling the atrioventricular opening. The cusps are fused at their attachment but part toward the centre of the opening. Each cusp is enforced by fibrous strands, the **chordae tendineae.**

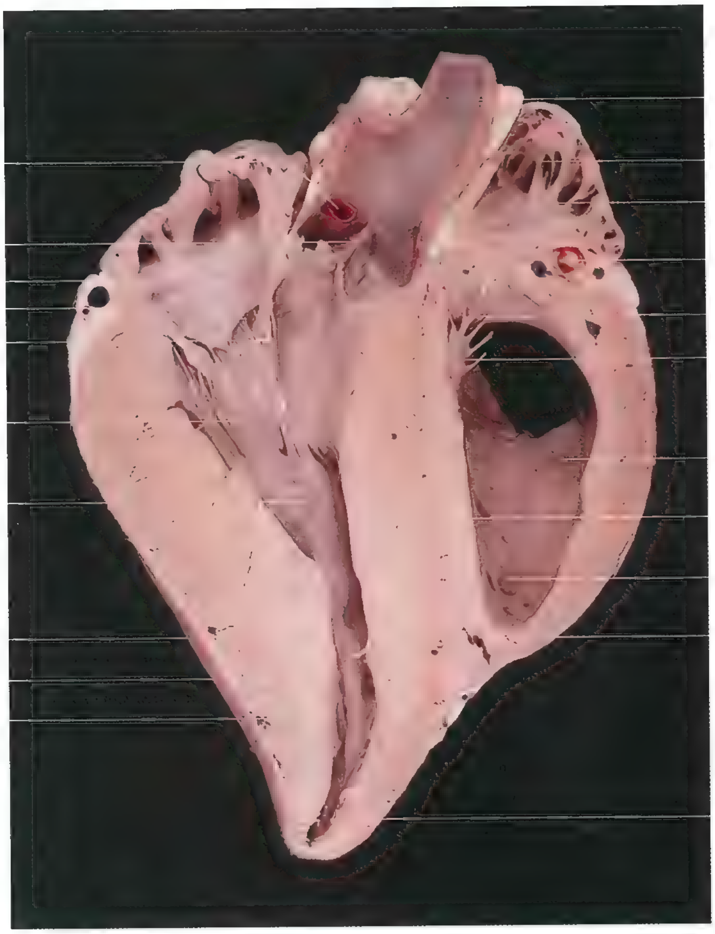

Fig. 12-7. Interior of a heart of a horse, longitudinal section (courtesy of PD Dr. J. Maierl, Munich).

The chordae tendineae arise from conical shaped muscular projections, the **papillary muscles** (mm. papillares) and extend to the free border and adjacent ventricular surface of the tricuspid valve. There are generally **three of these muscles** projecting from the ventricular walls and the interventricular septum into the interior of the chamber, with the largest (m. papillaris magnus) on the right ventricular free wall.

The **chordae tendineae** are so arranged that they connect each muscle to two cusps and each cusp to two muscles. This arrangement prevents the valve from prolapsing into the atrium, when the ventricles contract. The tricuspid valve is the **intake valve** to the **right ventricle** and prevents blood from returning from the ventricle to the right atrium during **systolic phase of the cardiac cycle.**

During **diastole** blood is prevented from flowing back from the pulmonary trunk into the right ventricle by the **pulmonary valve** (valva trunci pulmonalis) (Fig. 12-8). The pulmonary valve is located at the root of the pulmonary trunk and consists of **three semilunar cusps** (valvulae semilunares), that are deeply hollowed on the arterial side. The free ends of the **semilunar cusps** are thickened with a **nodule in the middle** (nodulus valvulae semilunaris), which accelerates closure of the valve.

The lumen of the right ventricle is crossed by a branched or single muscular band **(trabecula septomarginalis),** that passes from the interventricular septum to the outer wall (Fig. 12-6. The ventral part of the right ventricle is marked by numerous myocardial ridges **(trabeculae carneae),** that project mainly from the outer wall. They are thought to reduce blood turbulence.

Left ventricle (ventriculus sinister)

The left ventricle is conical in shape with its apex forming the apex of the heart (Fig. 12-6 and 7). It receives the oxygenated blood from the lungs by way of the pulmonary veins and the left atrium and pumps blood around the majority of the body, via the aorta. The walls of the left ventricle are thicker than the ones of the right, however the volume of both ventricles is the same. In the cat, there are two muscular bands crossing the interior of the ventricle from the outer wall to the **interventricular septum** (trabeculae septomarginalis).

The **left atrioventricular opening** (ostium atrioventriculare sinistrum) is occupied by the **left atrioventricular valve** (valva atrioventricularis sinistra), also known as mitral valve (Fig. 12-8 and 9). Its structure is similar to the right atrioventricular valve in form but consists of two cusps. Correspondingly there are only two papillary muscle in the left ventricle.

The **aortic orifice** (ostium aortae) is the opening from the left ventricle into the ascending aorta. It is closed by the

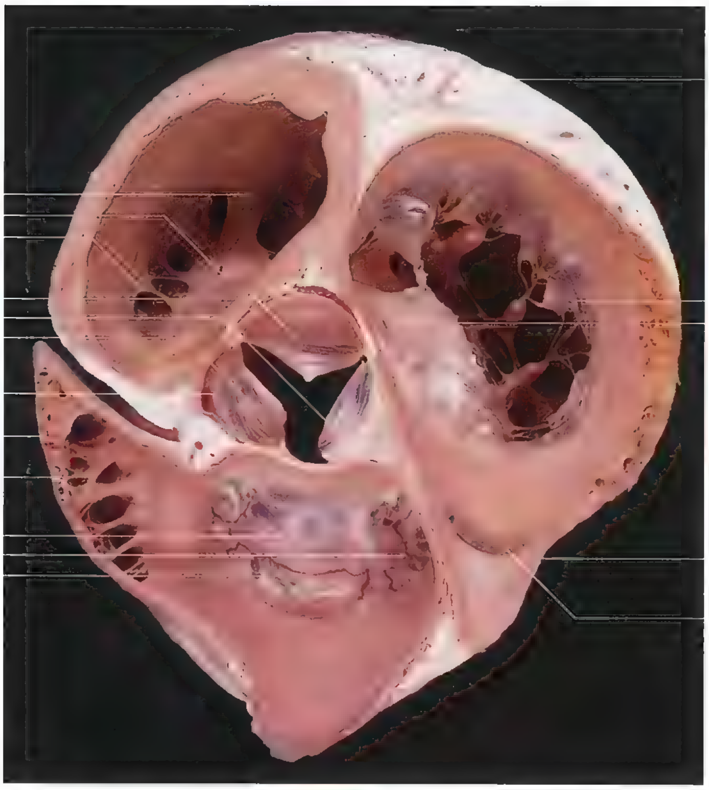

Fig. 12-8. Interior of the heart of a horse, transverse section through the atria (courtesy of PD Dr. J. Maierl, Munich).

aortic valve (valva aortae) during **diastole.** The aortic valve is similar to the pulmonary valve, but the nodular thickenings in the free margins of the aortic cusps are generally more conspicuous.

Peripheral to each of the semilunar cusps of the aortic valve, the wall of the aorta is dilated to form the three **aortic sinuses** (sinus aortae). The widening of the base of the ascending aorta, formed by the aortic sinuses, is the **aortic bulb** (bulbus aortae). The right and left coronary arteries leave the right and left aortic sinuses.

Structure of the cardiac wall

The wall of the heart consists of three layers (Fig. 12-7):

- Endocardium,
- Myocardium,
- Epicardium.

The **endocardium** is a thin, smooth layer that lines the cardiac chambers, covers the atrial auricles and is continuous with the lining of the blood vessels. The **epicardium** is part of the pericardium and described earlier in this chapter.

The **myocardium, or heart muscles,** makes up the majority of the cardiac wall. It consists of modified striated muscle fibres, which are characterised by central nuclei. They form end-to-end anastomoses with each other that results in an interlacing pattern with lighter **stripes** (disci intercalares) marking the junction between cells.

In contrast to conventional striated muscle, cardiac myocytes do not fatigue and are regulated by the **autonomic nervous system.** The myocardium of the atria is thin and generally arranged in arches, and forms loops around the vena cavae and pulmonary veins as they empty into the atria. The atrial musculature is attached to the fibrous base of the heart.

The **musculature of the ventricles,** like that of other hollow organs, is divided into deep longitudinal, middle circular and superficial longitudinal layers. All muscle fibres originate and insert on the fibrous base of the heart. The muscle bundles of the superficial layer run toward the apex, with a clockwise twist.

At the **apex of the heart** they turn around and pass towards the base in such a manner that they are perpendicular to the descending superficial fibres. Some of the superficial fibres passing toward the base, end at the papillary muscles. Some fibres penetrate and join with fibres of the middle layer. The middle layer constitutes the majority of the bulk of the ventricular walls. They are spiral or circular muscles that interdigitate between the two chambers.

The thickness and structure of the cardiac walls mirror the load to which each specific part of the heart is subjected. The walls of the atria, as blood receiving compartments with little contractile function, are thin. The walls of the ventricles, the main pumping chamber, are thick with the wall of the right ventricle **(pulmonary circulation)** being thinner than that of the left **(systemic circulation).**

The heart muscle can **hypertrophy** and/or **dilate** following a variety of disease states, including valvular stenosis or insufficiency and in dilated cardiomyopathy. Ventricular

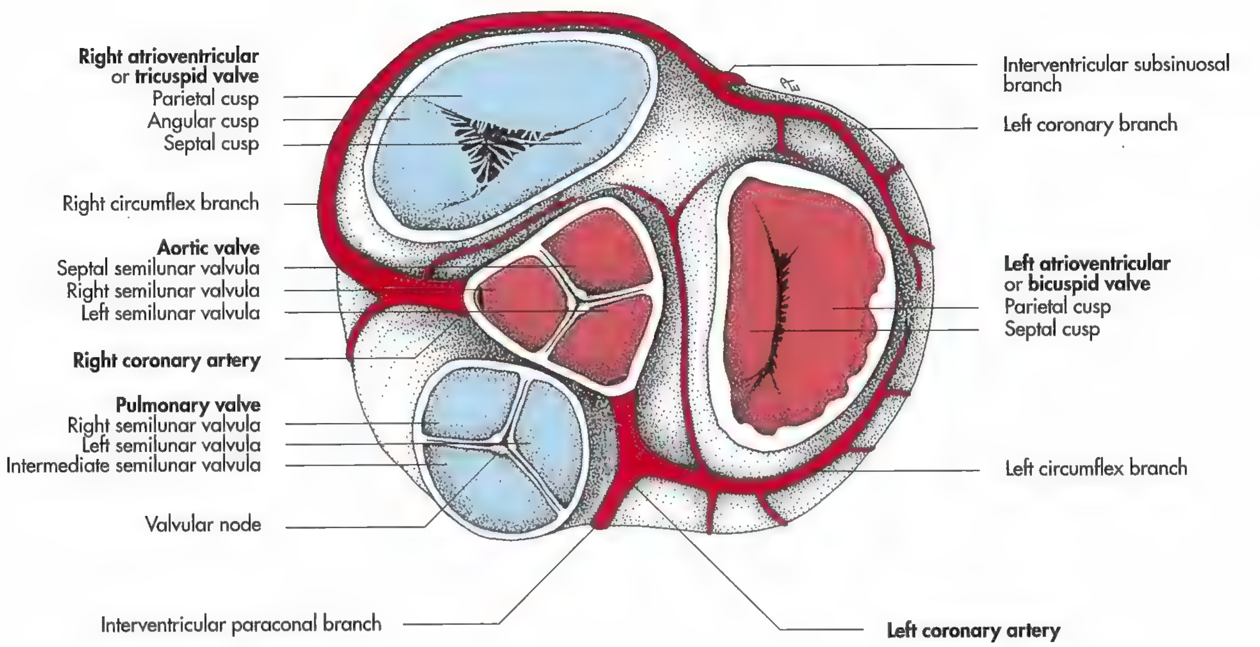

Fig. 12-9. Interior of the heart of a horse, transverse section through the atria, schematic.

enlargement can be visualised radiographically or ultrasonographically.

Blood vessels of the heart

The heart is well vascularised, receiving about 5% of the output of the left ventricle in man and even a higher percentage in animals, depending on the animals condition. Blood supply to the heart is provided the coronary arteries and their branches. They originate from two of the three sinuses above the semilunar valves at the root of the aorta (Fig. 12-7 to 9).

There are the:

- Left coronary artery (a. coronaria sinistra),
- Right coronary artery (a. coronaria dextra).

The **left coronary artery** is usually the larger and arises from the left sinus of the aortic bulb (Fig.12-7). It passes between the left auricle and the pulmonary trunk to the coronary groove, where it divides into the **interventricular paraconal branch** (ramus interventricularis paraconalis) and the **circumflex branch** (ramus circumflexus). The interventricular paraconal branch follows the like-named groove toward the apex of the heart and supplies the walls of the left ventricle and most of the septum. The circumflex branch continues in the coronary groove toward the caudal aspect of the heart (Fig. 12-9), where it terminates close to the right interventricular groove (horse and pig) or continues into the apex of the heart (carnivores and ruminants).

The **right coronary artery** arises from the right sinus of the aortic bulb and passes between the right auricle and the pulmonary trunk to the coronary groove. It continues around the cranial aspect of the base of the heart and either tapers toward the origin of the right interventricular groove (carnivores and ruminants) or turns into this groove. It extends to the apex of the heart in those species where the left coronary artery does not supply this area (horse and pig).

There is a **great deal of variation** in the pattern of coronary arteries in individuals, which is no clinical important in veterinary medicine. In contrast, this is of great clinical importance in human medicine with regards to infarct surgery. The coronary arteries are so-called end-arteries in that the end arteries do not form anastomoses. Thus vascular occlusion of one branch cannot be tolerated and leads to local infarction of the cardiac muscle. The clinical phenomenon of acute myocardial infarctions, being the most common cause of death in the western world, does not occur in any of the veterinary species.

Most of the coronary veins drain into the **great coronary vein** (v. cordis magna), which runs in parallel with the left coronary vein (Fig. 12-8). It returns to the right atrium by a short wide trunk, the coronary sinus. Shortly before it opens into the coronary sinus it is joined by the **middle coronary vein** (v. cordis media), which ascends in the right interventricular groove. Many of the **smaller veins** (vv. cordis minimae) open into the cavities of the heart directly.

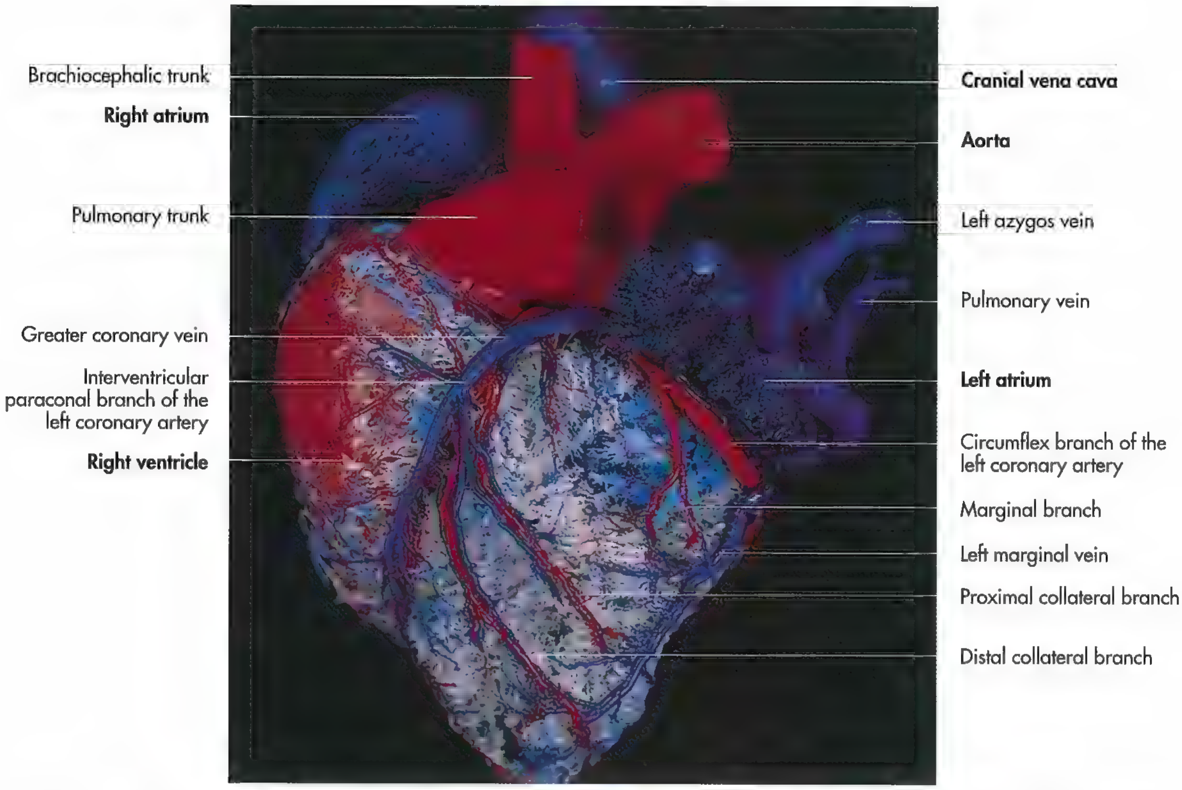

Fig. 12-10. Cardiac vessels of an ovine heart, corrosion cast, left aspect (courtesy of Prof. Dr. Ana Carretero and A. Oliver, Barcelona).

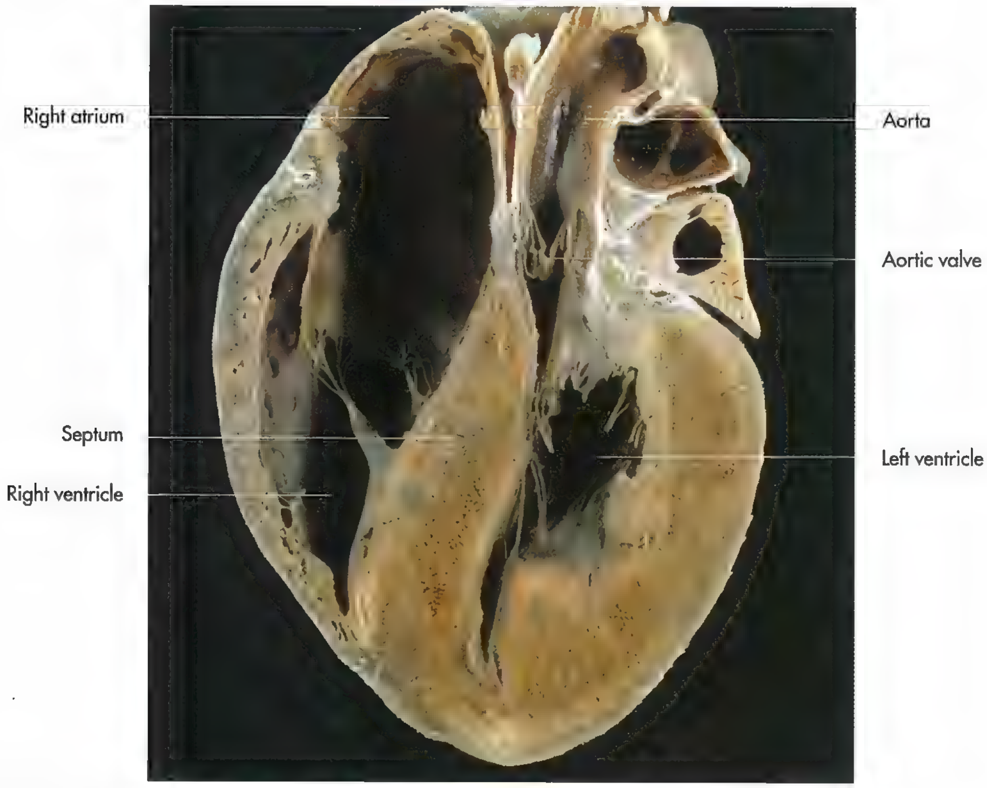

Fig. 12-11. Interior of the heart of a dog, longitudinal section (plastinate preparation).

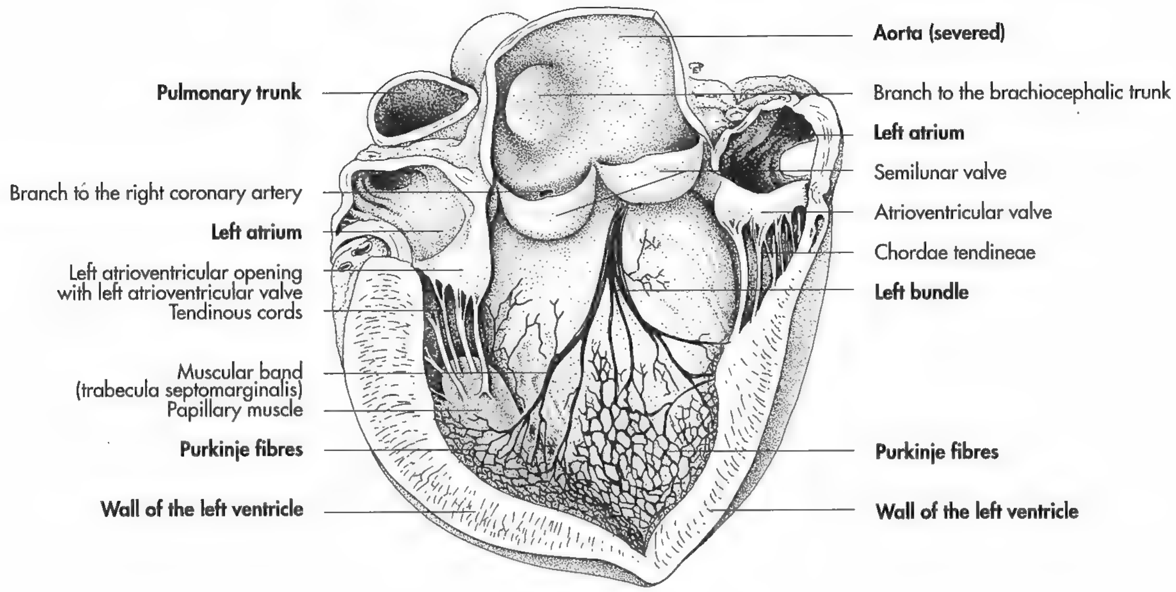

Fig. 12-12. Conducting system of the left atrium and ventricle, schematic.

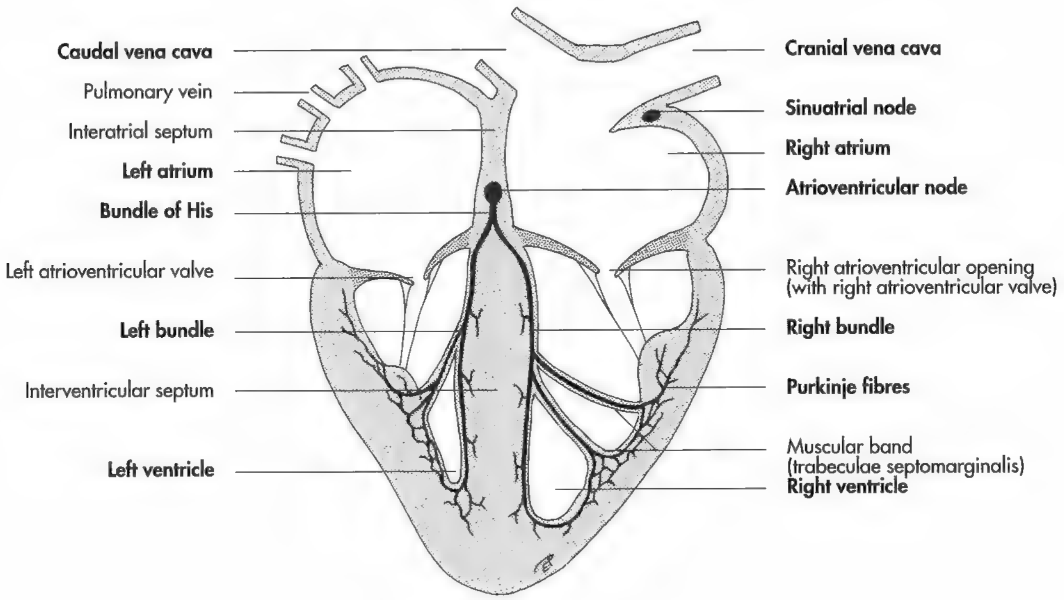

Fig. 12-13. Conducting system of the right and left ventricle, schematic.

Conducting system of the heart

The conducting system of the heart consists of modified myocytes. The diameter of the cells is greater, they contain more intracellular fluid and have a higher glycogen content, but fewer fibrils compared to the normal myocytes. The most characteristic feature of the conducting tissue is its capacity for spontaneous electrical activity, which spreads to the adjacent muscle, resulting in depolarisation and contraction. This guarantees cardiac autonomy essential for the inherent rhythm of the heart, although it is influenced by the autonomic nervous system.

The conducting system consists of the following parts (Fig. 12-12 and 13):

- Sinoatrial node (nodus sinuatrialis),
- Atrioventricular node (nodus atrioventricularis),
- Atrioventricular bundle or Bundle of His (fasciculus atrioventricularis),
  - Right bundle (crus dextrum),
  - Left bundle (crus sinistrum) and
- Subendocardial branches or Purkinje fibres (rami subendocardiales).

Although all parts of the conducting system are capable of spontaneous activity, the **sinoatrial node** is **autonomous,** by virtue of having the highest resting rate of **depolarisation.** As such, it initiates the cardiac cycle acting as the primary pacemaker overriding other pacemaker activity. This ensures co-ordinated contraction, which is essential for efficient pumping. Only if the sinoatrial node dysfunctions, do other parts of the system take over the role of dominant pacemaker, sequentially, this function is taken over by the **atrioventricular node,** or the **Purkinje fibres.**

The **sinoatrial node** is located below the **endocardium** of the **right atrial wall** ventral to the opening of the cranial vena cava. Although it does not form a conspicuous structure, visible to the naked eye. It is richly innervated by both the sympathetic and parasympathetic nervous systems. From the sinoatrial node the wave of excitement spreads to the surrounding muscle and reaches the **atrioventricular node,** which is located in the **interatrial septum** close to the opening of the coronary sinus (Fig. 12-13).

This node is also richly innervated and gives origin to the **atrioventricular bundle** (truncus fasciculi atrioventricularis), which penetrates the cardiac skeleton before dividing into **right** (crus dexter) and **left bundles** (crus sinister) (Fig. 12-13). These branches lie closely under the endocardium of the interventricular septum. The right branch crosses the cavity of the right ventricle in the septomarginal trabecula of this chamber. It ends in the outer ventricular wall of the right ventricle. The left branch is more diffuse and ramifies in the outer wall of the left ventricle. The final branches of these bundles are known as subendocardial branches or Purkinje fibres (Fig 12-13).

Innervation of the heart

Innervation of the heart is provided by the **autonomic nervous system.** Sympathetic fibres are supplied by the cervical cardiac nerves and the **caudal thoracic nerves,** (also called **nn. accelerantes** according to their function), which originate from the **stellate ganglion** and the **middle cervical ganglion.** The number of these nerves varies among species and even individuals. **Parasympathetic fibres** arise as branches of the **vagus nerve** either directly or from the recurrent laryngeal nerve. These nerve fibres are summarised under the term **depressor nerve** (N. depressor). (For a more detailed description see chapter 14, "Nervous system").

All nerve fibres form the **cardiac plexus** (plexus cardiacus) within the cranial mediastinum. Most of the sympathetic nerves are postganglionic fibres, whereas the parasympathetic fibres are **preganglionic.** These form synapses in small ganglia, which are located beneath the epicardium in the walls of the atria, mostly adjacent to the large blood vessels. Many of the fibres innervate the conducting tissue, especially the sinoatrial and the atrioventricular nodes. Efferent fibres of both the parasympathetic and the sympathetic system leave the heart. Sympathetic efferent fibres are responsible for pain receptors, while parasympathetic efferent nerves respond to increases in distension.

Cardiac function is not dependent on afferent nerves, but these influence both rate and force of contractions, to match cardiac output to the body's need for oxygen. Sympathetic stimulus accelerates the **pacemaker rate (chroniotropy)** and increase **contractility (ionotropy),** while parasympathetic innervation slows pacemaker rate. The heart both responds to circulating hormones, such as **adrenaline,** and has endocrine actions, for example the atrial cells produce **atrial natriuretic peptide,** a peptide hormone, which plays a role in the regulation of blood pressure.

Lymphatics of the heart

The heart tissue is drained by **lymph capillaries,** which become confluent in small lymph vessels beneath the epicardium. These run toward the base of the heart, where they form bigger lymph vessels close to the junction between the coronary groove and the left interventricular groove. These finally drain into the cranial and caudal **mediastinal lymph nodes** and the **tracheobronchial lymph nodes.**

Function of the heart

Alternating between contraction and relaxation results in a pumping action, that makes the blood circulate through the body. The phase of contraction is called **systole,** relaxation is called **diastole.** During systole the atria of the heart contract first, followed by a contraction of the ventricles, which takes about double the time of the latter. The atrioventricular node is of vital importance for the delay between atrial and ventricular contraction, ensuring complete ventricular filling. The walls of the ventricle contract almost simultaneously with the papillary muscles preventing the prolapse of the valve cusps into the atria. The longitudinal layers of the myocardium shorten the ventricles so that the apex is pulled toward the base of the heart. The circular muscle fibres of the left ventricle and the septum contract like a sphincter. Only contraction of the right ventricular free wall plays a part in right ventricular outflow.

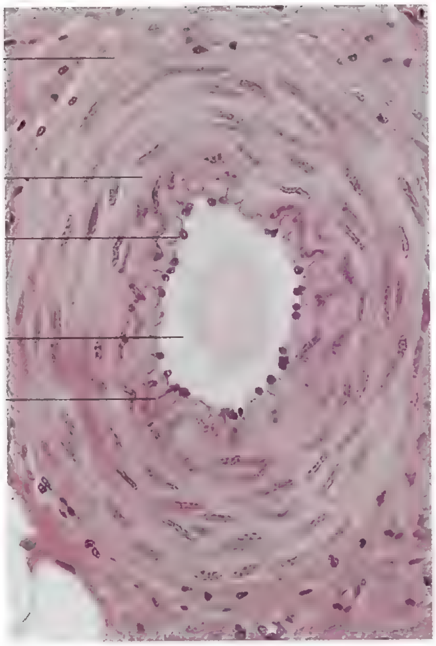

Fig. 12-14. Histological section of an artery.

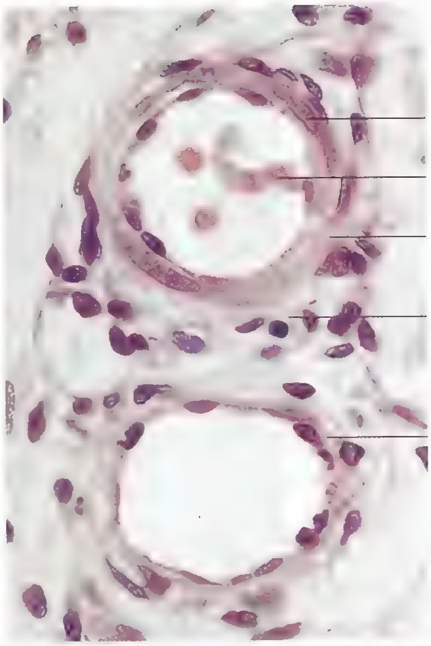

Fig. 12-15. Histological section of an arteriole and a venule.

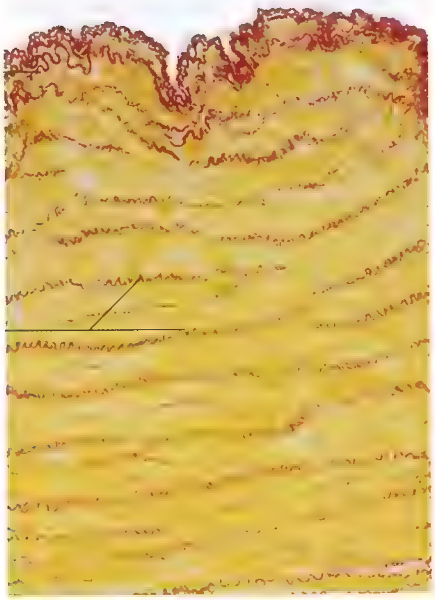

Fig. 12-16. Histological section of the wall of an artery.

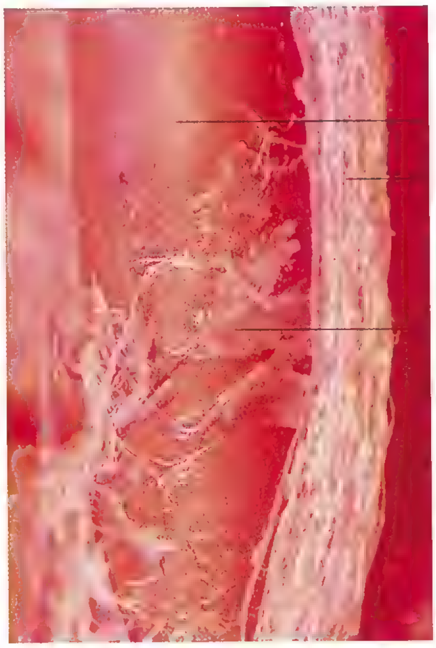

Fig. 12-17. Vasa vasorum and vasa nervorum of a large artery, corrosion cast.

The **volume of blood,** pumped by the heart during systole is termed stroke volume. In a 20 kg dog this measures approximately 11 ml, which amounts to 1.5 tons of blood in a day. **Cardiac output** is the product of stroke volume and heart rate, and is measured in litres of blood per minute. **Cardiac index** is the cardiac output corrected for body weight.

During **diastole** the myocardium relaxes and the heart chambers to fill passively. The return of the blood to the heart is assisted by several factors, such as ventilation, contraction of the diaphragm. The atrioventricular valves are open and the semilunar valves are closed during diastole. Backflow of blood against the coronary sinus is responsible for the coronary blood flow. Since blood flow relies on pressure differences, coronary flow is affected by both diastolic blood pressure and right atrial pressure.

The heart can be clinically evaluated by assessing heart rate and rhythm, palpation of pulse pressure, measurement of blood pressure and central venous pressure and by auscultation of the heart. Closure of the heart valves produces distinctive sounds, which are audible with a **stethoscope.** There are **four heart**

Fig. 12-18. Pulmonary vessels of a sheep, ventral aspect, corrosion cast (courtesy of Prof. Dr. M. Navarro and A. Oliver, Barcelona).

sounds referred to as S4 (atrial sound), S1, S2 and S3. Usually it is only possible to hear all four sounds in some horses, whereas S1 and S2 should be audible in all domestic animals.

The **first heart sound (S1)** is produced by the simultaneous closure of the atrioventricular valves at the beginning of systole. The **second heart sound (S2)** is produced by the simultaneous closure of the aortic and pulmonic valves, marking the beginning of diastole. The **third heart sound (S3)** is produced by passive ventricular filling, whilst the **fourth,** or **atrial, sound (S4)** is produced by atrial contraction.

The area where the sounds are most clearly heard are called **point of maximal intensity** and in the horse these are:

- **Left thorax,** at the level of a horizontal line drawn through the shoulder joint:
  - 3rd intercostal space: pulmonary valve,
  - 4th intercostal space: aortic valve,
  - 5th intercostal space: bicuspid valve,
- **Right thorax:**
  - 4th intercostal space: tricuspid valve.

Vessels (vasa)

Angiology (Angiologia) is the study of the form, structure, topography and function of vessels. Under clinical circumstances, it is more useful to have a basic general knowledge in angiology than to know the exact topography of each vessel in minute details, which in the author's opinion is only of academic interest. Therefore, the aim of this chapter is to provide students and practitioners with a sound working knowledge of angiology.

Structure of the vessels

All vessels have the same structure (Fig. 12-14 to 17) and are composed of three concentric layers:

- Internal layer (tunica interna),
- Middle layer (tunica media),
- External layer (tunica adventitia).

The **internal layer** is a single layered epithelium (endothelium), supported by a layer of subendothelial connective tissue (stratum subendotheliale) with an underlying basal membrane. This layer is responsible for the exchange of molecules and cells from the blood into the adjacent tissues. The **middle layer** is composed of a network of elastic tissue and smooth muscle in varying proportions. Pulsatory contraction of this layer plays an important role with regards to haemodynamics.

The **external layer** is predominantly connective tissue, which blends with the surrounding tissue and conveys autonomous nerve fibres to the vessels. It limits expansion of the vessel, safeguarding against spontaneous rupture. A more detailed description of the structure of vessels can be found in histology textbooks.

Lymph vessels have a similar construction to blood vessels, but are thinner-walled. They are described in chapter 13, "Immune system and lymphatic organs".

Blood vessels (vasa sanguinea)

The blood vessels form a continuous circulating system, that is more than 40 000 km long in humans. It is composed of:

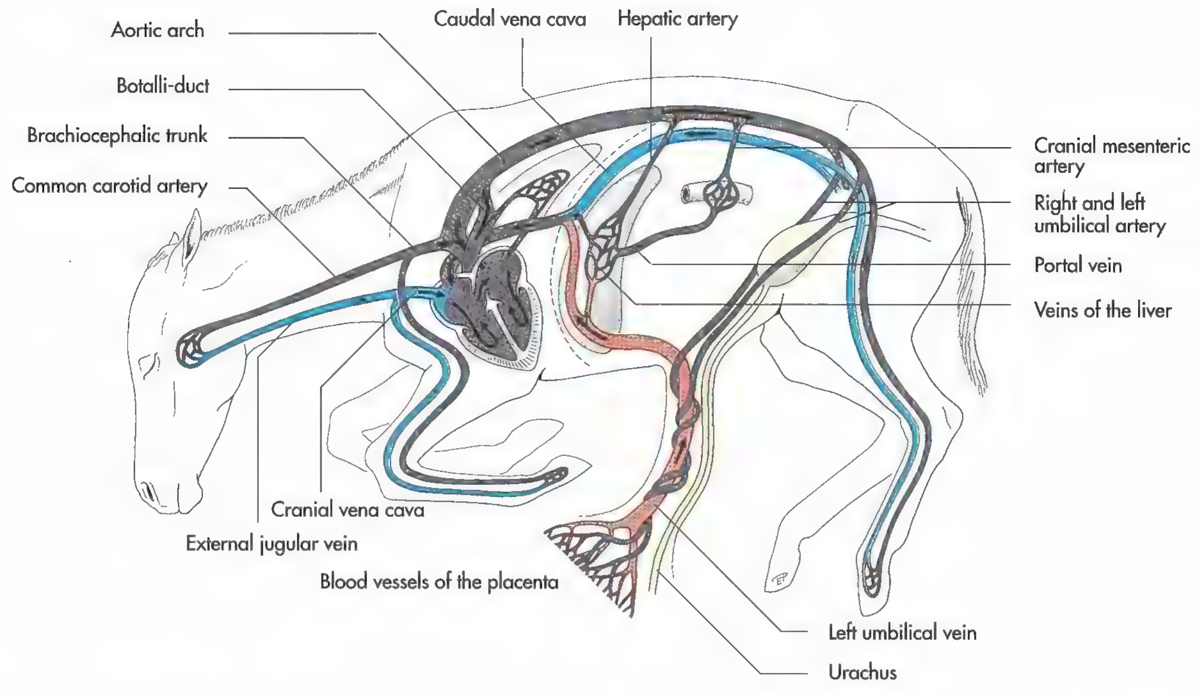

Fig. 12-19. Fetal circulatory system of the foal.

- Arteries (arteriae),
- Arterioles (arteriolae),
- Capillaries (capillaria),
- Venules (venulae) and
- Veins (venae).

Arteries and their smallest branches, the arterioles carry blood from the heart to body tissues and organs. Veins and their smallest branches, the post-capillary venules carry blood from the periphery to the heart. Capillaries are the minute connections between the arterioles and the venules.

Arteries (arteriae)

Based on the differences in structure of the tunica media, arteries can be grouped in two major classes: the **elastic type** and the **muscular type.** The first part of the **aorta** and some of its major branches and the pulmonary trunk are **elastic,** or **conducting type arteries.**

These arteries are required to expand considerably when they receive the **systolic output of the ventricles.** The tunica media is predominantly composed of elastic tissue with relatively little muscle. The elastic tissue stretches to absorb and store the energy of the moving blood stream during systole. In diastole this energy is released, maintaining forward flow of blood towards the periphery.

Arteries, which are further away from the heart, have a tunica media consisting largely of **smooth muscle cells.** The diameter of these muscular, or distributing, type of arteries are closely controlled by an **autonomic innervation.**

Arterioles are the smallest arteries. The muscular component is reduced to a few layers that are progressively lost. They principally regulate resistance to the blood flow and hence the peripheral blood pressure by constriction or dilation. Most arteries divide to form collateral branches before they terminate in capillary beds. Most of these collateral branches connect with neighbouring vessels, forming **arterioarterial anastomoses.** Thus if the principal trunk is occluded, collateral arteries maintain blood supply and the affected tissue may survive.

However some arteries, for example in the brain, heart and kidneys are so-called **endarteries,** which do not form anastomoses and occlusion will result in ischaemia of the tissue.

In some cases there are anastomoses, but the collateral connections are of insufficient diameter to maintain blood supply.

Highly modified arterial structures are the so-called **retia mirabilia.** A rete mirabile is formed by a main trunk, which divide into a series of parallel vessels, which in turn reunites to form one single vessel. This arrangement is found on the arteries to the **brain** and on a much smaller scale in the **renal glomeruli.** Because of their close relationship to their associated veins, they enhance venous return. It is also hypothesised that they slightly decrease blood temperature and pulsation of the blood to the brain.

While diffusion of nutrient components from the lumen into the blood vessel walls is sufficient to supply smaller vessels, the oxygen demand of larger vessels require supplementation by an intramural circulation. The arteries **(vasa vasorum)** penetrate the external layer of the major vessels from the outside and form a dense network within the external and part of the middle layers (Fig. 12-17).

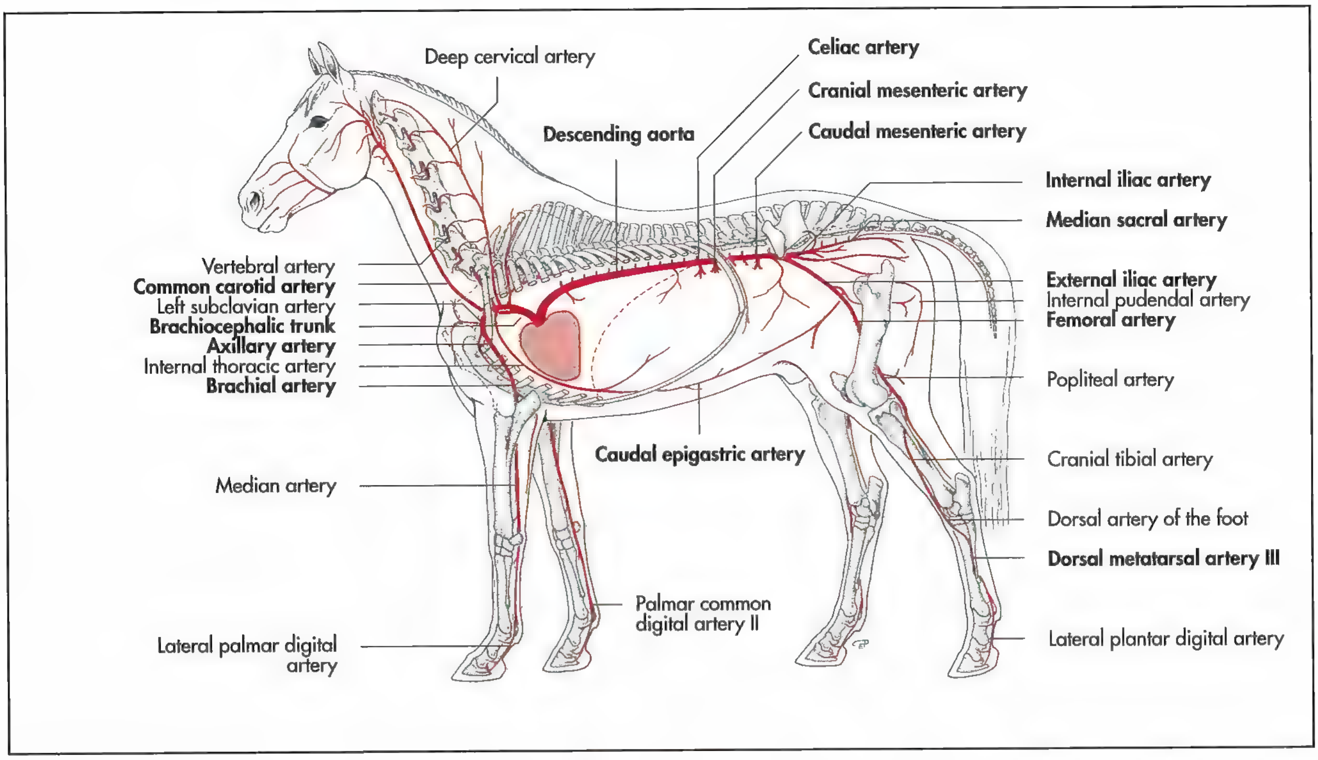

Fig. 12-20. Main branches of the aorta of the horse, schematic.

Arteries of the pulmonary circulation

Deoxygenated blood is transported from the right ventricle to the lung by the **arteries of the pulmonary circulation,** which comprises the pulmonary trunk and the left and right pulmonary arteries (Fig. 12-18). The **pulmonary trunk** (truncus pulmonalis) arises from the right ventricle from which it is separated by the **semilunar cusps** (valvulae semilunares) of the **pulmonary valve** (valva trunci pulmonalis). It passes between the two auricles and continues caudally to the left of the aorta. Close to its bifurcation it is attached to the aorta by the ligamentum arteriosum, a connective tissue remnant of the ductus arteriosus, which conveys blood directly into the aorta without passing through the lung in the foetal circulation (Fig. 12-19).

Ventral to the bifurcation of the trachea the pulmonary trunk divides into **right** and **left pulmonary arteries** (a. pulmonalis dextra et sinistra). Each artery each passes to the corresponding lung, where their branches follow the bronchi until they terminate in the basket-shaped capillary beds surrounding the alveoli. From these capillary beds arise the **pulmonary veins,** which convey the oxygenated blood to the left atrium. The **pulmonary arteries** are the only arteries in the body that carry deoxygenated blood.

Arteries of the systemic circulation

Since species differences are too numerous for the scope of this book, the horse will be used as a model (Fig. 12-20), but the most significant comparative features will be mentioned.

The arteries of the systemic circulation comprise the arteries, which **transport the oxygenated blood** from the left ventricle of the heart, to the organs and body tissues. The systemic circulation starts with the aorta, which is separated from the left ventricle by the aortic valve (Fig. 12-9). The initial portion of the aorta is enlarged to form the aortic bulb, from which the coronary arteries arise.

The **aorta ascends** (aorta ascendens) on the right side of the **pulmonary trunk** before it makes an U-turn dorsocaudally and to the left as the **aortic arch** (arcus aortae). The ascending aorta passes caudally and reaches the vertebral column at the level of the sixth thoracic vertebra slightly to the left of the median plane and continues from there as the **descending aorta** (aorta descendens) (Fig. 12-20).

The descending aorta can be further subdivided into a **thoracic portion** (aorta thoracica) and an **abdominal portion** (aorta abdominalis). It passes from the thoracic cavity into the abdominal cavity through an opening in the diaphragm **(hiatus aorticus).** At the level of the caudal lumbar vertebrae it divides into its terminal branches.

The **aortic arch** is joined to the pulmonary trunk by the **ligamentum arteriosum,** the remnant of the **fetal ductus arteriosus** (Fig. 12-19). Immediately after birth, when the new-born starts to breathe, the tunica media of the ductus arteriosus contracts and the inner tunic starts to transform. Normally the lumen of the vessel is obliterated within the first week postpartum.

A **persistent ductus arteriosus** results in a characteristic continuous type murmur audible by auscultation on the right and left hemithorax. The condition can cause hypoxaemia,

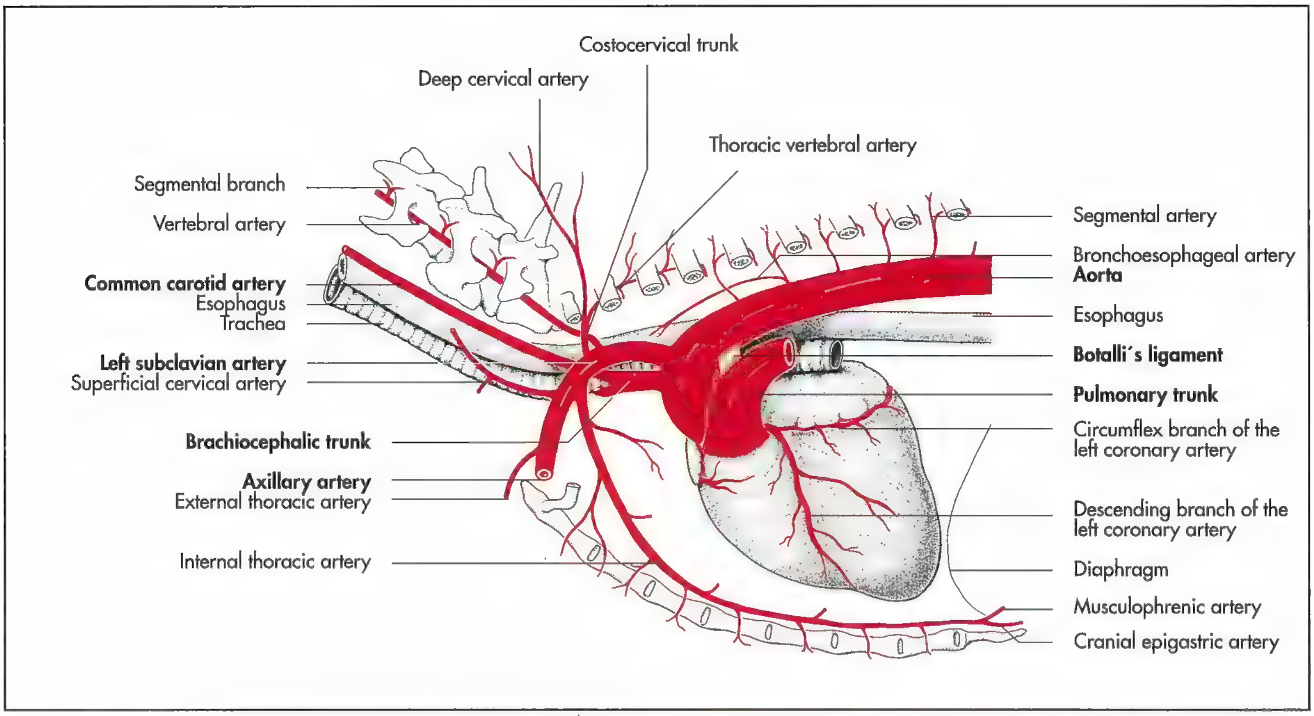

Fig. 12-21. Arteries of the base of the heart and the cranial mediastinum of the dog, schematic, left lateral aspect (Ellenberger and Baum, 1943).

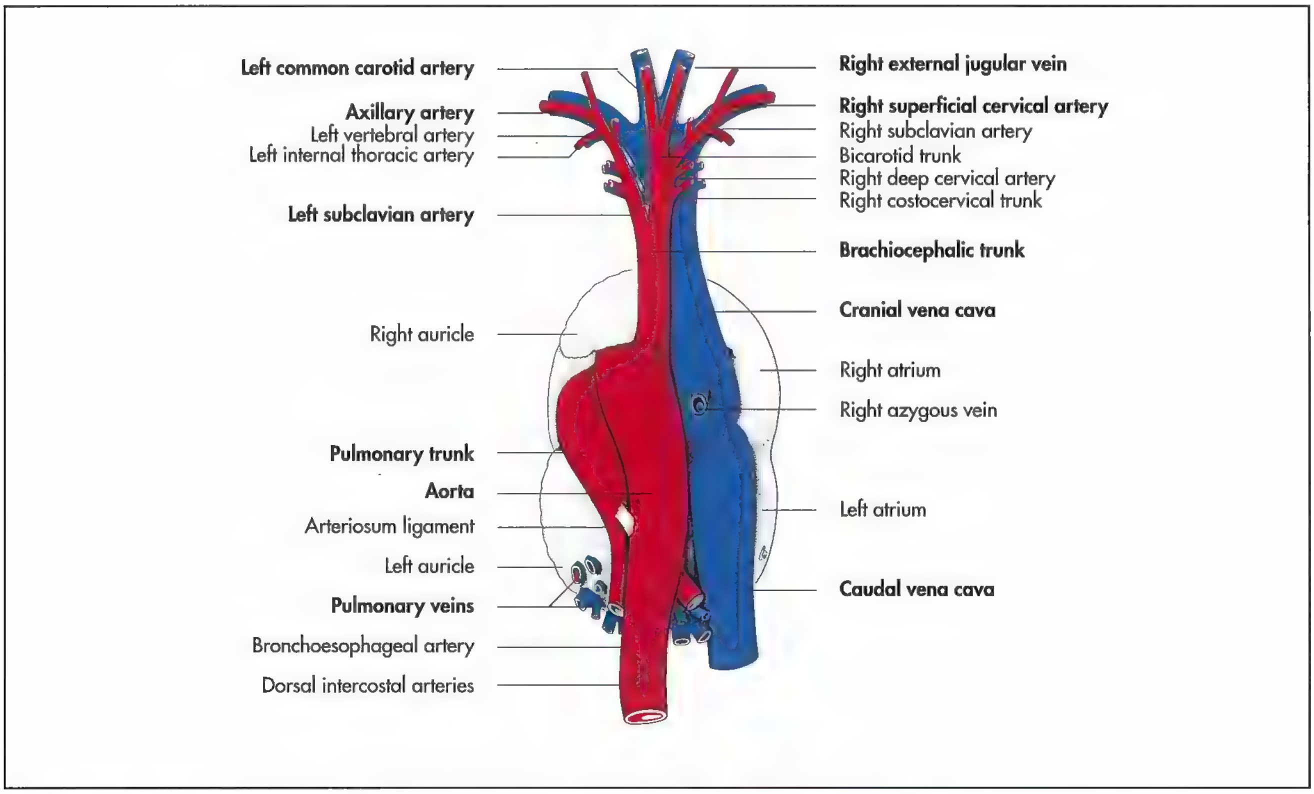

Fig. 12-22. Blood vessels at the base of the heart of the horse, dorsal aspect, schematic (Ghetie, 1967).

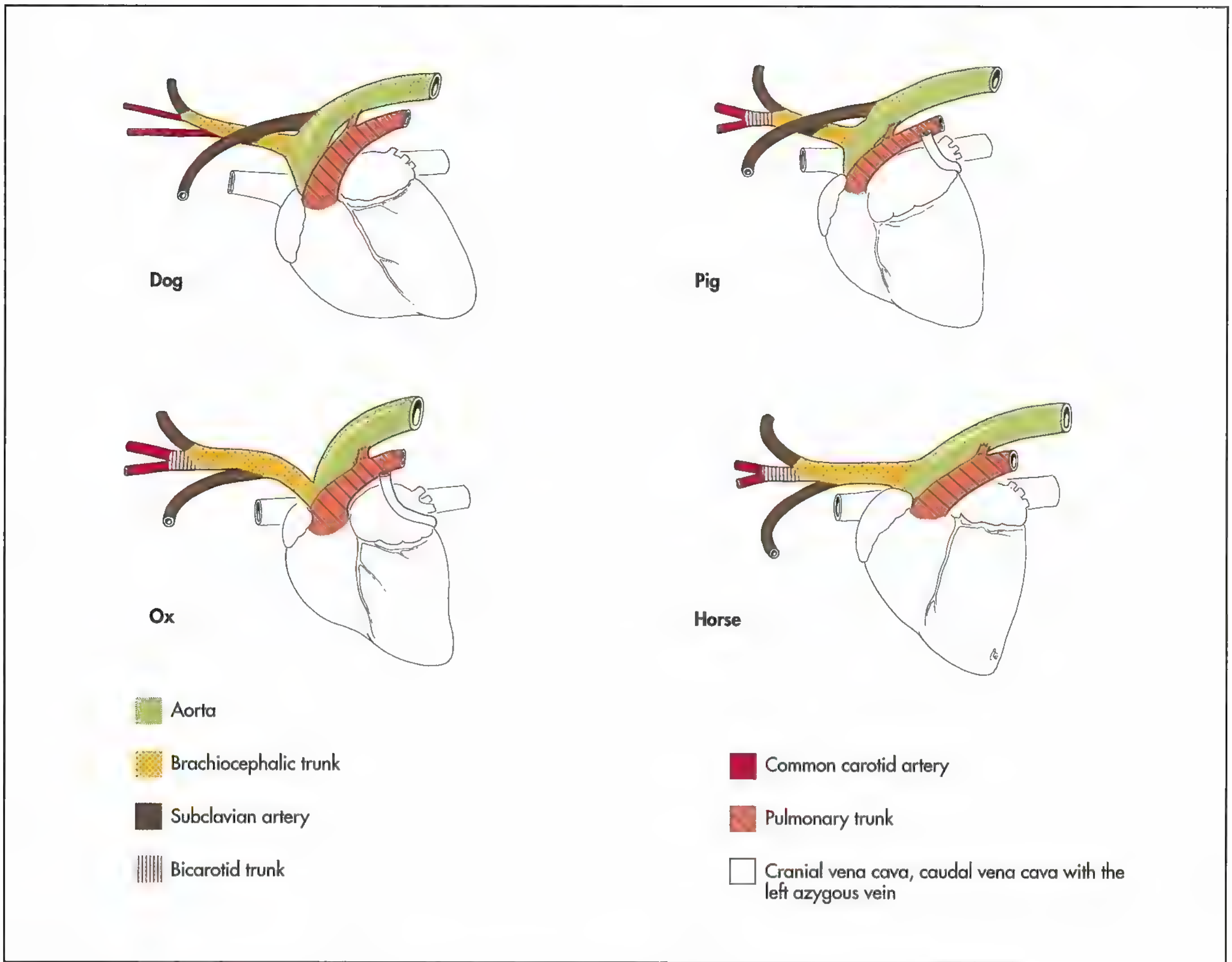

Fig. 12-23. Comparison of the vessels at the base of the heart of the domestic mammals, schematic (Ghetie, 1967).

due to mixing of oxygenated and deoxygenated blood within the peripheral arterial blood supply.

The **ascending aorta** originates from the left portion of the 4th branchial artery during embryonic development, the pulmonary trunk from the 6th (a more detailed description can be found in embryology textbooks). In some animals, such as the German Shepherd Dogs the ascending aorta has reportedly developed from the right portion of the 4th branchial artery, resulting in a condition termed "Persistent Right Aortic Arch".

In affected animals, the ligamentum arteriosum crosses the dorsal aspect of the esophagus causing a partial obstruction that can lead to the formation of diverticulum. Affected animals develop regurgitation of food material as the animal begins to eat solid type food-stuffs after weaning. Surgical dissection of the impinging ligament will correct the defect, although many animals can be managed without the need for surgery.

Cranial branches of the aortic arch

Brachiocephalic trunk

The brachiocephalic trunk arises from the aortic arch and branches cranially (Fig. 12-20 to 22). It provides the blood supply for the thoracic limbs, the neck, the head and the ventral portion of the thorax.

The brachiocephalic trunk gives origin to the:

- Left subclavian artery (a. subclavia sinistra),
- Right subclavian artery (a. subclavia dextra),
- Bicarotid trunk (truncus bicaroticus).

In the pig, cat and dog, the left subclavian artery takes a separate, more distal origin from the aortic arch.

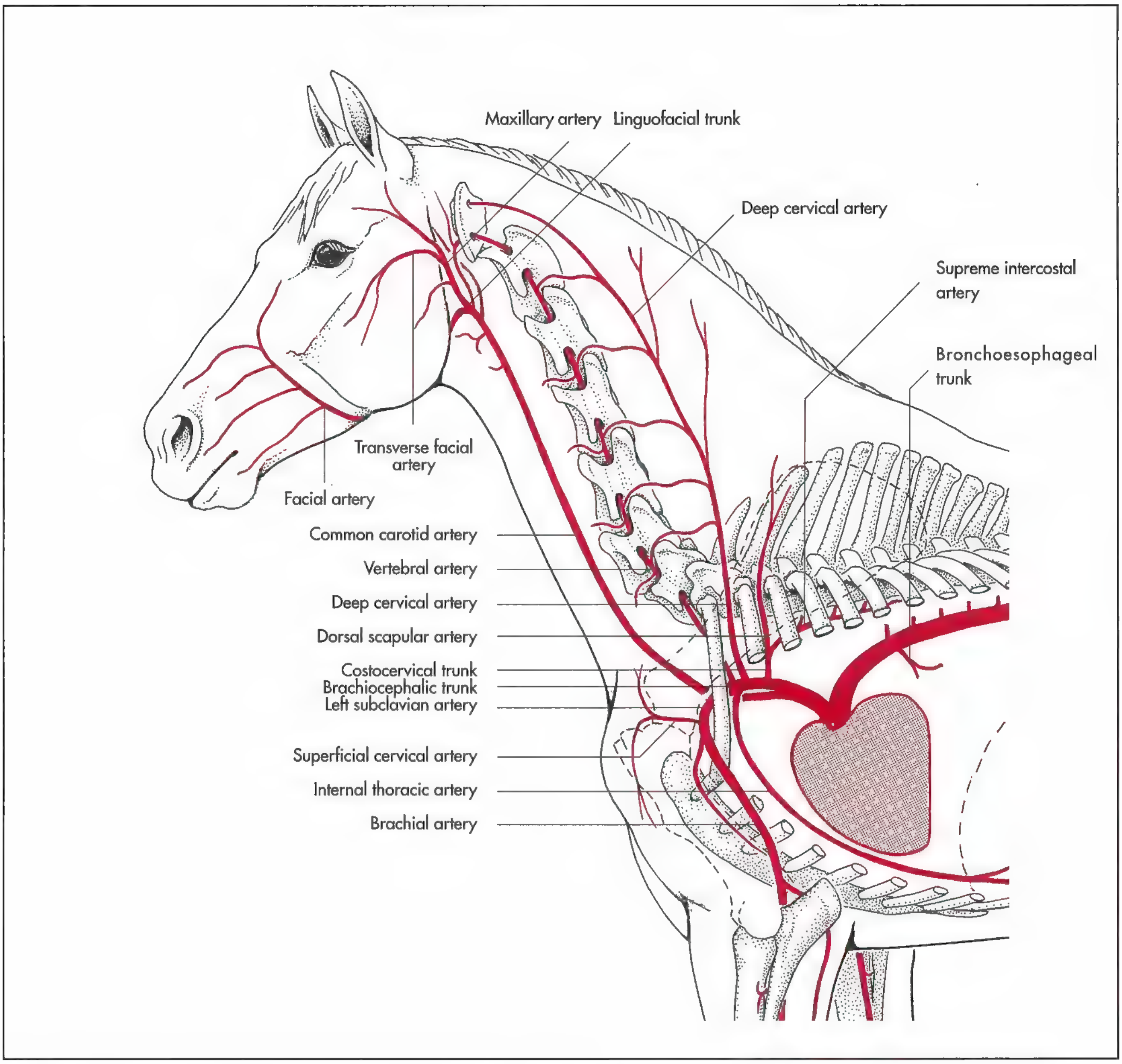

Fig. 12-24. Brachiocephalic trunk and its branches in the horse, schematic.

Subclavian artery

The subclavian arteries supplies blood to the forelimbs, the neck and cranial and ventral parts of the thorax.

Branches of the subclavian artery (Fig. 12-21 to 24):

- Costocervical trunk (truncus costocervicalis),
- Supreme intercostal artery (a. intercostalis suprema),
- Dorsal scapular artery (a. scapularis dorsalis),
- Deep cervical artery (a. cervicalis profunda),
- Vertebral artery (a. vertebralis),
- Superficial cervical artery (a. cervicalis superficialis),
- Internal thoracic artery (a. thoracica interna):
  - Musculophrenic artery (a. musculophrenica),
  - Cranial epigastric artery (a. epigastrica cranialis),
- Axillary artery (a. axillaris), the direct continuation of the subclavian artery.

The first branch, that arises from the subclavian artery is the **costocervical trunk,** which divides into the supreme intercostal artery, which branches, at the base of the neck and around the withers, to the supreme intercostal artery (in the dog the thoracic vertebral artery), that supplies the first few intercostal arteries. In the dog, the deep cervical artery is the dorso-

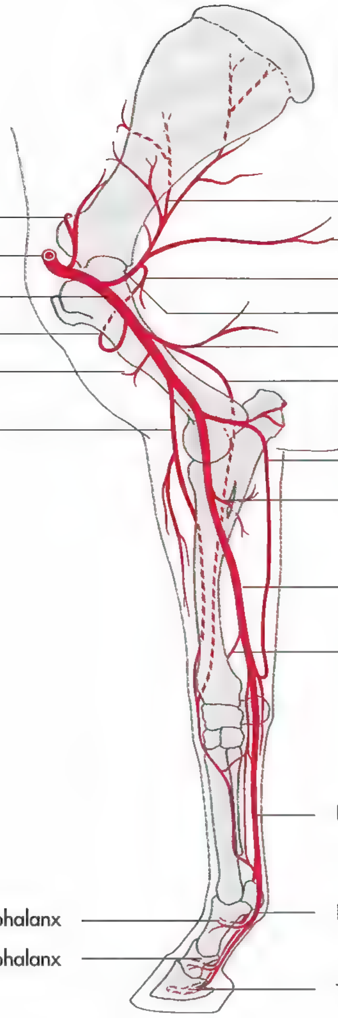

Fig. 12-25. Arteries of the thoracic limb of the horse, medial aspect, schematic (Ellenberger and Baum, 1943).

cranially extending terminal branch of the costocervical trunk, while in large animals the substantial deep cervical artery arises directly from the subclavian artery (Fig. 12-24). It provides blood supply to the dorsal cervical musculature up to the nuchal region.

The **vertebral artery** passes cranially through the transverse canal, formed by the successive transverse foramina of the cervical vertebrae, and enters the vertebral canal within the atlas. During this path, it sends muscular branches into the adjacent cervical musculature and spinal branches into the vertebral canal. In the ox, the vertebral artery also vascularises caudal parts of the brain. This fact is of importance with regards to religious slaughtering rituals, by which the common carotid artery is cut to kill the animal. In these animals, the EEG shows a much longer brain activity, compared to animals slaughtered by humane techniques.

The **superficial cervical artery** vascularises the ventral part of the base of the neck.

The **internal thoracic artery** runs caudally above the sternum and detaches intercostal branches. It ends at the diaphragm by dividing into the musculophrenic artery, which supplies the diaphragm and the cranial epigastric artery, which passes to the stomach, where it forms an anastomosis with the caudal epigastric artery.

Several anastomoses are formed between the **deep cervical artery** and the **vertebral artery,** as well as between the vertebral artery and the occipital artery.

After detaching the above branches, the subclavian artery winds around the cranial border of the first rib to enter the forelimb, where it changes its name to the axillary artery (Fig. 12-25 to 27). Branches of the axillary artery (and structures they supply) are:

Fig. 12-26. Arteries of the thoracic limb of a sheep, lateral aspect, corrosion cast (courtesy of Prof. Dr. M. Navarro and A. Oliver, Barcelona).

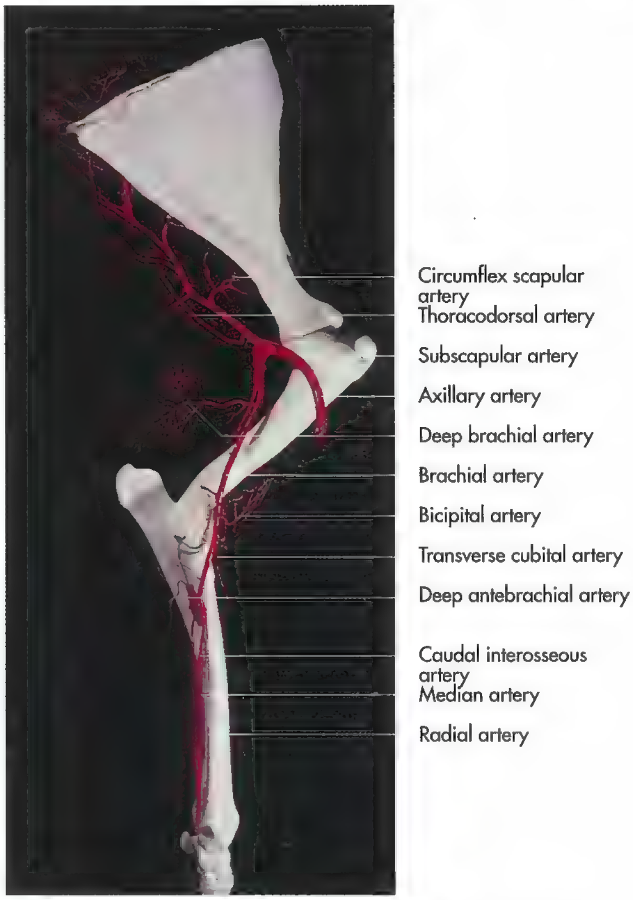

Fig. 12-27. Arteries of the thoracic limb of a sheep, medial aspect, corrosion cast (courtesy of Prof. Dr. M. Navarro and A. Oliver, Barcelona).

Axillary artery (a. axillaris):
- Suprascapular artery (a. suprascapularis): supraspinous muscle,
- Subscapular artery (a. subscapularis)
  – Caudal circumflex humeral artery (a. circumflexa humeri caudalis): triceps muscle,
  – Circumflex scapular artery: infraspinous and subscapular muscle
- Thoracodorsal artery (a. thoracodorsalis): major teres, latissimus dorsi muscle.

Brachial artery (a. brachialis):
- Cranial circumflex humeral artery (a. circumflexa humeri cranialis): proximal biceps, coracobrachial, major teres and latissimus dorsi muscles,
- Deep brachial artery (a. profunda brachii): triceps muscle,
  – Radial collateral artery (a. collateralis radialis),
- Bicipital artery (a. bicipitalis): biceps muscle,
- Transverse cubital artery (a. transversa cubiti): radial extensor muscle,
- Ulnar collateral artery (a. collateralis ulnaris),
- Common interosseous artery (a. interossea communis),
- **Median artery** (a. mediana)
  – Radial artery (a. radialis): carpal joint,
  – Palmar carpal rete (rete carpi palmare),
  – Dorsal carpal rete (rete carpi dorsale),
- **Medial palmar artery** (a. digitalis palmaris communis II)
  – Medial and lateral digital palmar artery (a. digitalis palmaris medialis et lateralis).

The original part of the **axillary artery** is closely related to the axillary plexus. After the detachment of the suprascapular, the subscapular and the thoracodorsal arteries, it changes its name again at the level of the axillary lymph nodes where it becomes the brachial artery. The **brachial artery** continues distally into the thoracic limb as its main blood supply. It runs parallel to its corresponding vein and the median, ulnar and musculocutaneous nerve. In the cat, the brachial artery and the median nerve pass through the **supracondylar foramen** at the proximal end of the radius, while the vein passes around the shaft of the humerus. It detaches several branches into the surrounding muscles. In the dog, the superficial brachial artery leaves the brachial artery at the distal third of the humerus and passes distally on the cranial aspect of the radius, carpus and metacarpus to reach the digits, where it branches out to form the dorsal digital arteries.

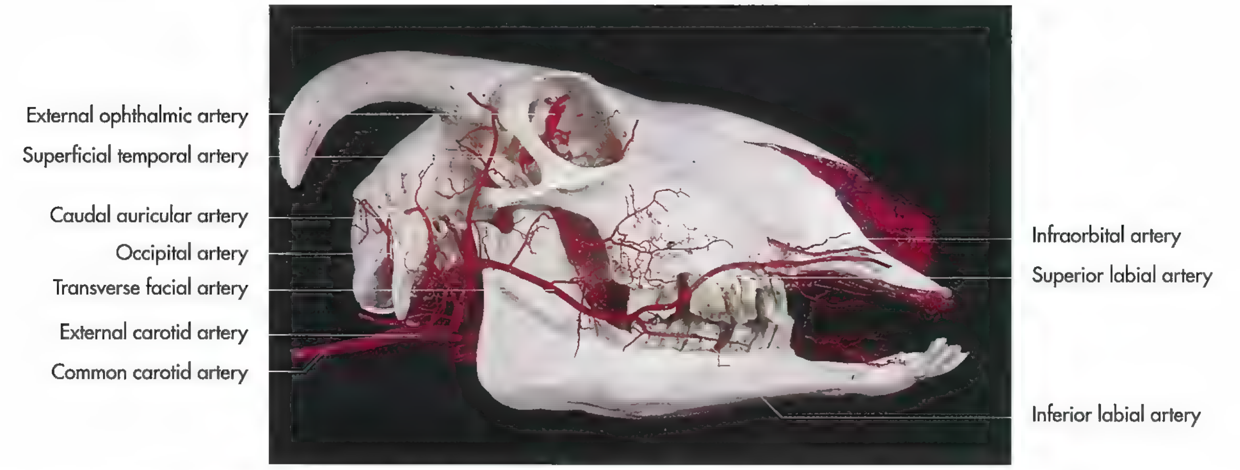

Fig. 12-28. Superficial arteries of the head of a sheep, corrosion cast (courtesy of Prof. Dr. Ana Carretero and A. Oliver, Barcelona).

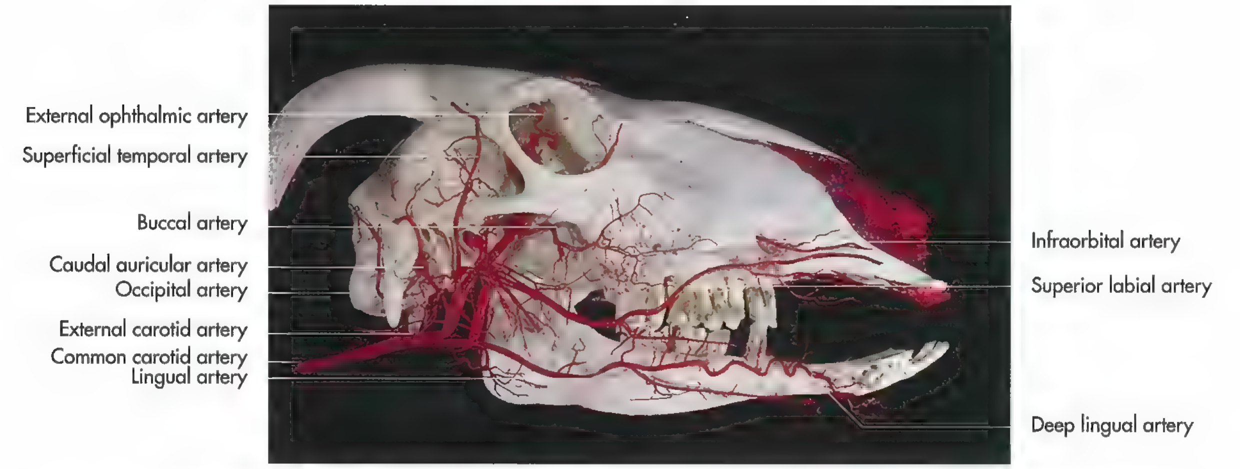

Fig. 12-29. Deep arteries of the head of a sheep, corrosion cast (courtesy of Prof. Dr. Ana Carretero and A. Oliver, Barcelona).

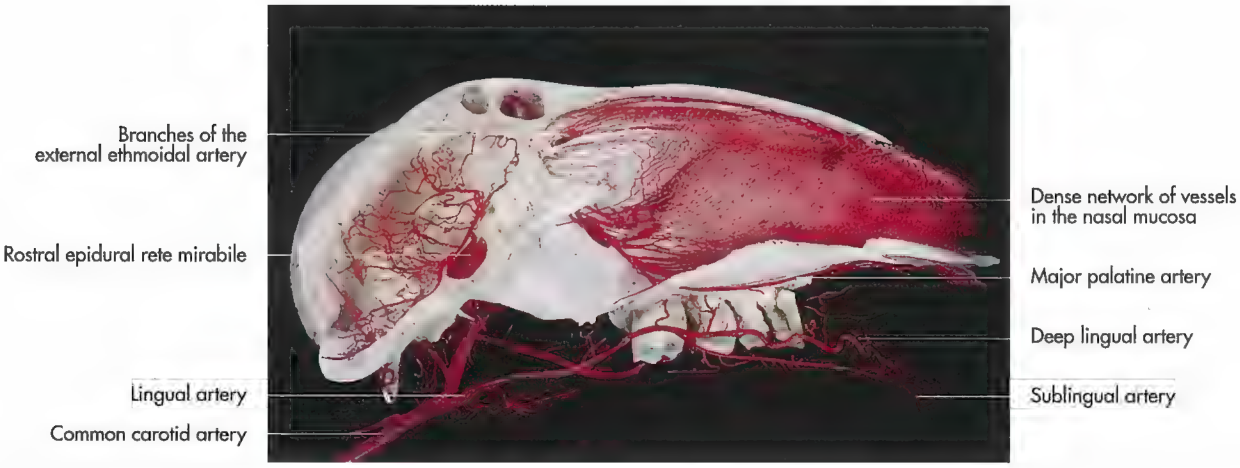

Fig. 12-30. Arteries of the cranial and nasal cavity of a sheep, median section, corrosion cast (courtesy of Prof. Dr. Ana Carretero and A. Oliver, Barcelona).

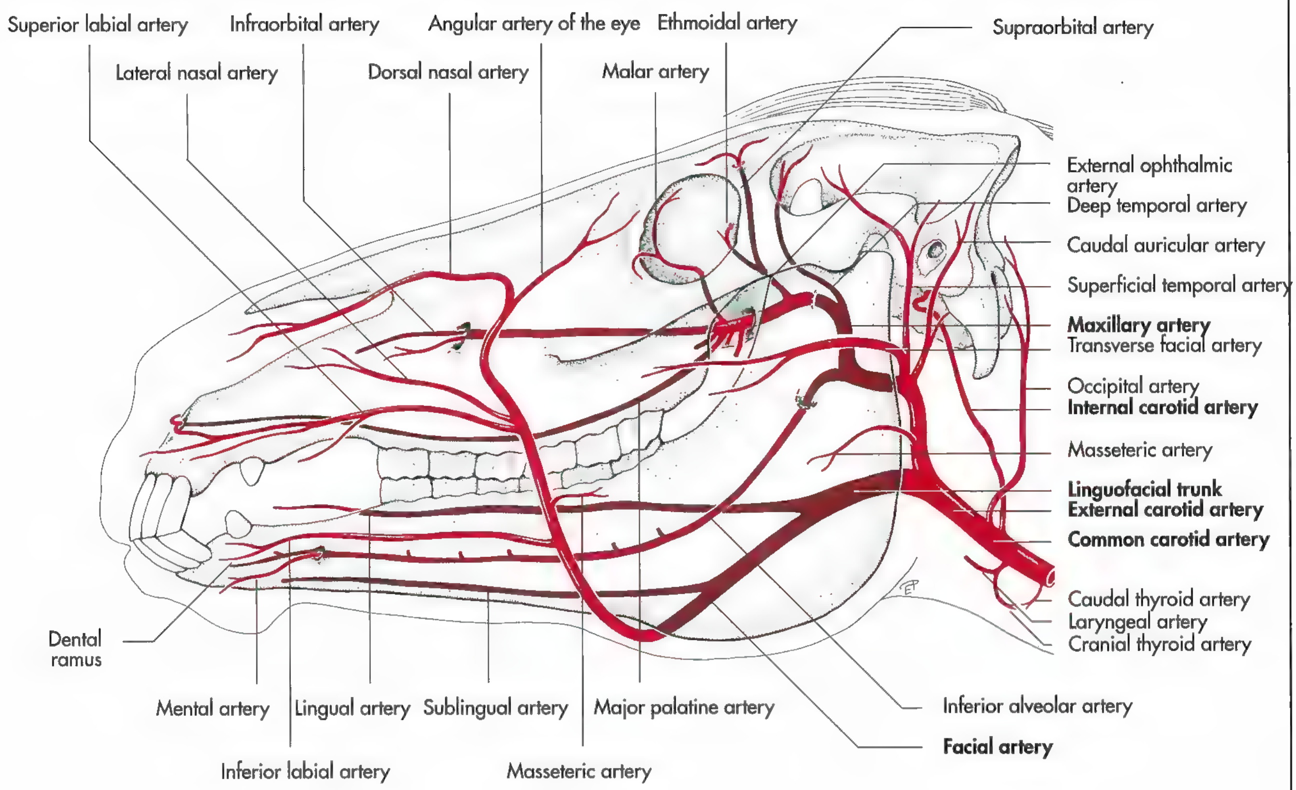

Fig. 12-31. Main arteries of the head of the horse, schematic (Dyce et al., 1991).

The **brachial artery** becomes the median artery in the proximal antebrachium after detachment of the **common interosseous artery.** The median artery runs down the caudomedial aspect of the forearm together with the median nerve and under the flexor carpi radialis muscle. It passes through the carpal canal with the digital flexor tendons and provides branches for the **carpal rete** at the level of the carpus. It continues in the region of the third metacarpal bone, where it becomes the **medial palmar artery (palmar common digital artery II),** the main artery to the digit and hoof. This further divides into the medial and lateral palmar digital arteries above the metacarpophalangeal joint. The **digital arteries** pass over the abaxial aspects of the proximal sesamoid bones, where the digital pulse is palpable. The branches of the digital arteries distal to the metacarpophalangeal joint are symmetrical and the two arteries form the terminal arch in the third phalanx. Several arteriovenous anastomoses are present and arterial pulsation enhances venous return.

The main branches of the axillary artery form several anastomoses with each other from which small arteries arise.

Clinically important landmarks:

- Arterial blood sampling site: The axillary artery can be injected, where it winds around the cranial border of the first rib.
- Pulse palpation: The pulse of the brachial artery is palpable on the medial aspect of the elbow joint, the digital pulse is palpable at the abaxial aspect of the proximal sesamoid bones.

Bicarotid trunk

The bicarotid trunk is a short common trunk, which arises from the brachiocephalic trunk, extends cranially and branches into the left and right common carotid arteries (Fig. 12-22 and 23). In the dog and cat the common carotid arteries arise separately from the brachiocephalic trunk, the origin of the right being distal to the left. Therefore these animals do not have a bicarotid trunk.

The **common carotid arteries** ascend the neck to each side of the trachea accompanied by the vagosympathetic trunk and the caudal (recurrent) laryngeal nerve. Except for some small branches to the esophagus, the trachea and the adjacent muscles, the only significant branches are detached close to its termination. These are the **caudal** and **cranial thyroid arteries** (Fig. 12-31), both of which provide the blood supply for the thyroid gland.

The **cranial thyroid artery** gives origin to the cranial laryngeal artery for the larynx and the ascending pharyngeal artery for the pharynx. In the horse the common carotid artery ends by dividing into the **external** and **internal carotid artery** and the **occipital artery** (Fig. 12-31). Close to this division lies the **carotid body** (glomus caroticum), a chemoreceptor, which responds to changes in blood pressure. The **occipital artery** provides blood supply to the muscles of the nuchal region, the caudal meninges, the middle and internal ear before it anastomoses with the vertebral artery, thus taking part in the supply to the brain.

The **internal carotid artery** enters the cranial cavity after forming a characteristic s-shaped flexure at the base of the skull in the horse and dog. In the horse the internal carotid artery passes through the guttural pouch, a diverticulum of the auditory tube, peculiar to the horse. Erosion of the vessel wall in horses with guttural pouch mycosis causes bleeding, which can be fatal. In the horse and the dog, the internal carotid artery is responsible for vascularisation of the brain. In the other domestic mammals this is achieved by branches of the maxillary artery, that form retia mirabilia at the base of the brain, which reunite to form the cerebral carotid artery (see chapter 14 "Nervous System"). The arterial blood supply of the brain is closely related to the **cavernous sinus** (sinus cavernosus), which provides venous drainage of the cranial cavity.

The **external carotid artery** is the largest of the terminal branches of the common carotid artery and appears as the direct continuation of the parent trunk. It continues as the **maxillary artery** and detaches several branches to provide the blood supply to the muscles, bones and organs of the head, other than the brain (Fig. 12-28 to 31). Branches of the **common carotid artery** and their vascularised structures:

- **Caudal thyroid artery**
  (a. thyreoidea caudalis): thyroid gland,
- **Cranial thyroid artery**
  (a. thyroidea cranialis): thyroid gland,
  – Cranial laryngeal artery
  (a. laryngea cranialis): larynx,
  – Ascending pharyngeal artery
  (a. pharyngea ascendens): pharynx,
- **Occipital artery** (a. occipitalis): nuchal musculature,
  – Caudal meningeal artery
  (a. meningea caud.): Meninges,
- **Internal carotid artery** (a. carotis interna): brain,
- **External carotid artery,**
- **Linguofacial artery** (a. linguofacialis),
  – Ascending palatine artery
  (a. palatina ascendens): pharynx,
  – Lingual artery (a. lingualis): tongue,
  – Sublingual artery (a. sublingualis): tongue,
- **Facial artery** (a. facialis),
  – Inferior labial artery
  (a. labialis inferior): face, lower lip,
  – Superior labial artery
  (a. labialis superior): face, upper lip,
  – Lateral nasal artery (a. lateralis nasi): face, nose,
  – Dorsal nasal artery (a. dorsalis nasi): face, nose,
  – Angular artery of the orbit
  (a. angularis oculi): face, eye lids,
  – Masseteric artery
  (a. masseterica): masseter muscle,
    – Transverse facial artery
    (a. transversa faciei): masseter muscle,
    – Caudal auricular artery
    (a. auricularis caudalis): external ear,
    – Rostral auricular artery
    (a. auricularis rostralis): external ear,

Branches of the **maxillary artery** and their vascularised structures:

- **Inferior alveolar artery** (a. alveolaris inferior)
  – Alveolar branches (rami alveolares): lower teeth,
  – Mental artery (a. mentalis): mental angle,
- **Caudal deep temporal artery**
  (a. temporalis profunda caudalis): temporal muscle,
- **Rostral deep temporal artery**
  (a. temporalis profunda rostralis): temporal muscle,
- **Middle meningeal artery**
  (a. meningea media): meninges,
- **Malar artery** (a. malaris): orbit,
- **Sphenoplatine artery** (a. sphenopalatina): nasal cavity,
- **Greater palatine artery** (a. palatina major): hard palate,
- **Lesser palatine artery** (a. palatina minor): soft palate,
- **Infraorbital artery**
  (a. infraorbitalis): teeth, maxilla, nose,
- **External ophthalmic artery** (a. ophthalmica externa)
  – Supraorbital artery (a. supraorbitalis): frontal region,
  – Ethmoid artery (a. ethmoidalis): ethmoid, orbit,
  – Lacrimal artery (a. lacrimalis): lacrimal gland,
  – Rostral meningeal artery
  (a. meningea rostralis): meninges,
  – Internal ophthalmic artery
  (a. ophthalmica interna): retina.

The numerous smaller branches of the arteries of the head are demonstrated in Fig. 12-28 and Fig 12-30 for the sheep. In this species the transverse facial and the infraorbital artery provides the blood supply to the face. Branches of the maxillary artery forms a large rete mirabile at the base of the skull.

Clinically important landmarks:
- Pulse palpation in the horse: Facial artery at the facial notch on the ventral border of the mandible.
- Arterial blood sampling: Linguofacial artery at the facial notch on the ventral border of the mandible, common carotid artery at the base of the neck, transverse facial artery ventral to the temporomandibular joint.

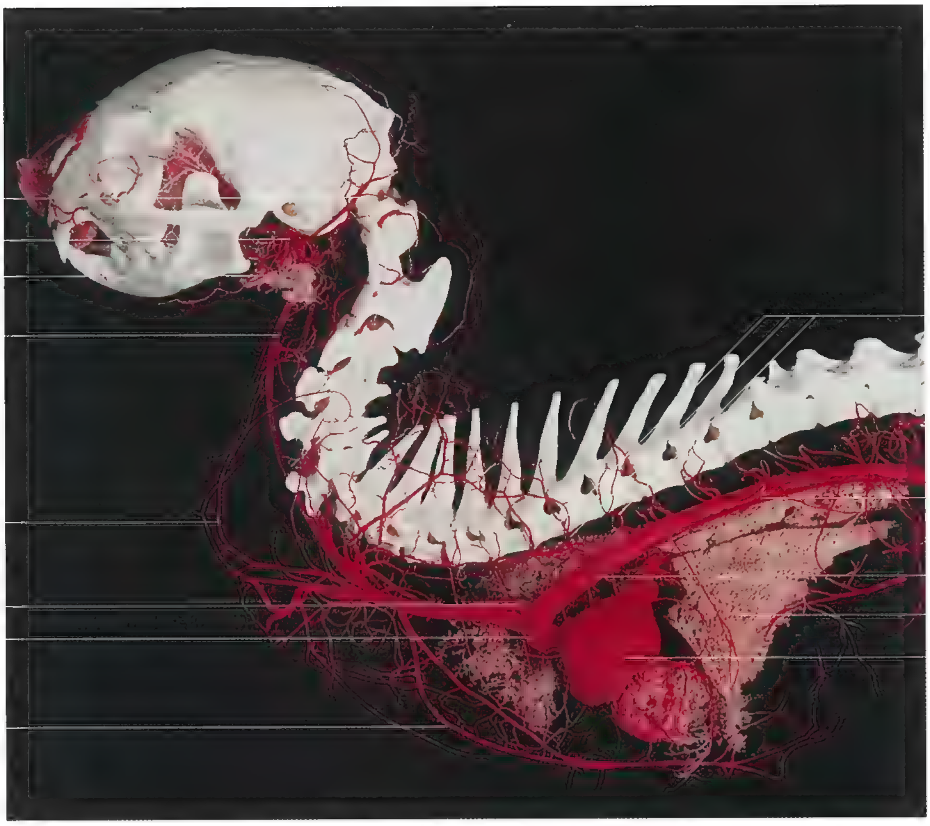

Fig. 12-32. Arteries of the thoracic cavity and the cervical region of a cat, corrosion cast (courtesy of Prof. Dr. M. Navarro and A. Oliver, Barcelona).

Thoracic aorta and abdominal aorta

The thoracic artery passes caudally below the spine to enter the abdomen by the **aortic hiatus** of the diaphragm, from which it continues caudally as the **abdominal aorta.** Both detach segmental arteries, which are called dorsal **intercostal arteries** (aa. intercostales dorsales) in the thorax (Fig. 12-32) and **lumbar arteries** (aa. lumbales) in the abdomen. These arteries supply the wall of the thorax and abdomen and send branches **(rami spinales)** to the spinal cord. The spinal branches enter the spinal canal through the corresponding intervertebral foramen (see chapter 14, "Nervous system").

They vascularise the spinal ganglia, the meninges and end in the ventral spinal artery, that runs in the central groove on the ventral aspect of the spine along its whole length. In the cervical region, the ventral spinal artery forms anastomoses with the vertebral and occipital artery. In the sacral and caudal region, the spinal cord is supplied by the **median sacral** and the **coccygeal artery.** Branches and vascularised structures of the **thoracic aorta** (Fig. 12-32):

- **Dorsal intercostal arteries:** thoracic and abdominal wall, spinal cord,
- **Bronchoesophageal artery** (a. bronchooesophagea),
  - Bronchial branches (rami bronchiales): bronchial tree,
  - Ephageal branches (rami oesophagei): esophagus,
- **Costoabdominal artery** (a. costoabdominalis): abdominal wall
- **Cranial phrenic artery** (a. phrenica cranialis), present in the horse only: diaphragm.

Branches and vascularises structures of the **abdominal aorta** (Fig. 12-33 to 36):

- **Caudal phrenic artery** (a. phrenica caudalis), present in all the domestic mammals, other than the horse: diaphragm,
- **Celiac artery** (a. coeliaca): for the vascularised structures see chapter 7,
  - Left gastric artery (a. gastrica sinistra),
  - Hepatic artery (a. hepatica),
    - Right gastric artery (a. gastrica dextra),
    - Right gastroepiploic artery (a. gastroepiploica dextra),
  - Splenic artery (a. lienalis),
    - Left gastroepiploic artery (a. gastroepiploica sinistra),

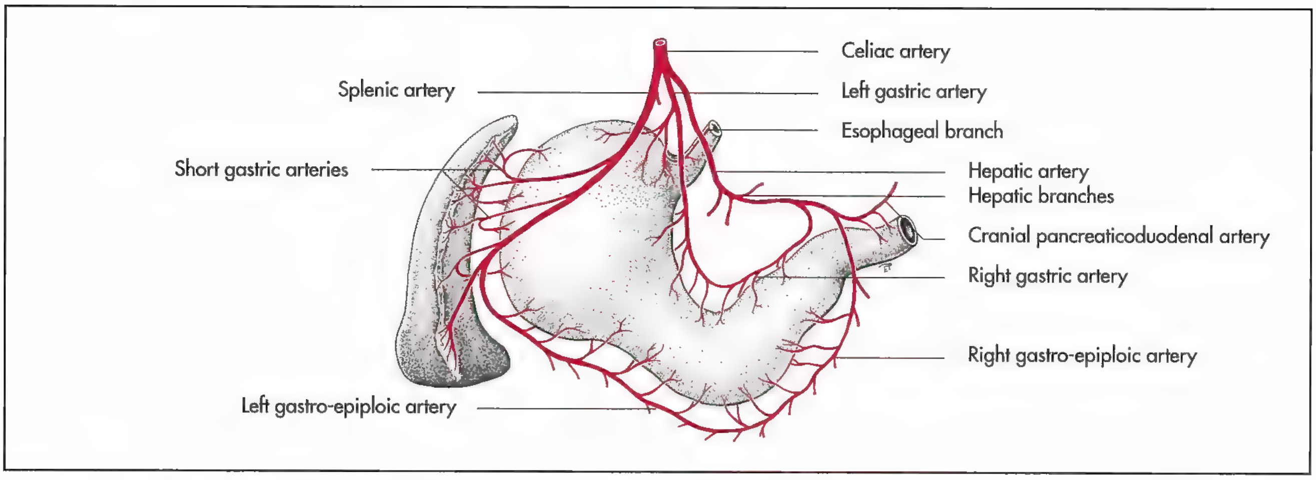

Fig. 12-33. Celiac artery of the dog, schematic.

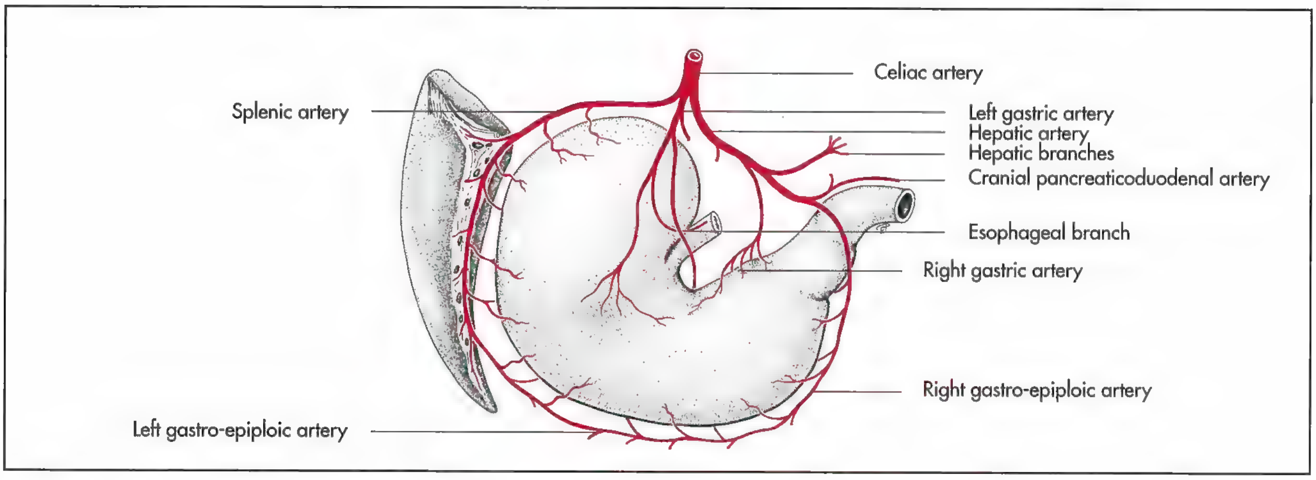

Fig. 12-34. Celiac artery of the horse, schematic.

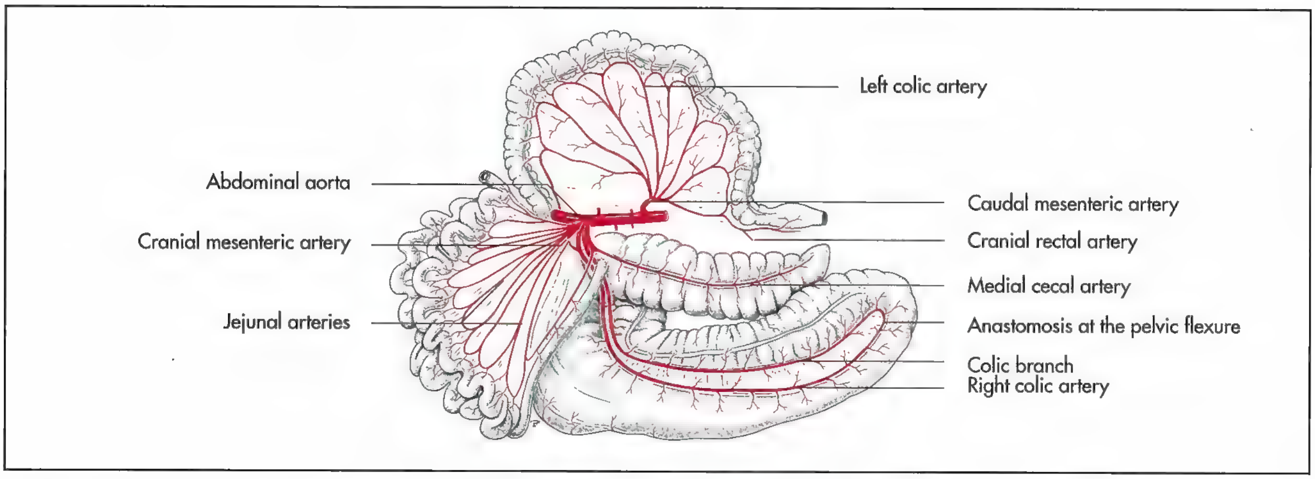

Fig. 12-35. Cranial and caudal mesenteric artery of the horse, schematic (Ghetie, 1955).

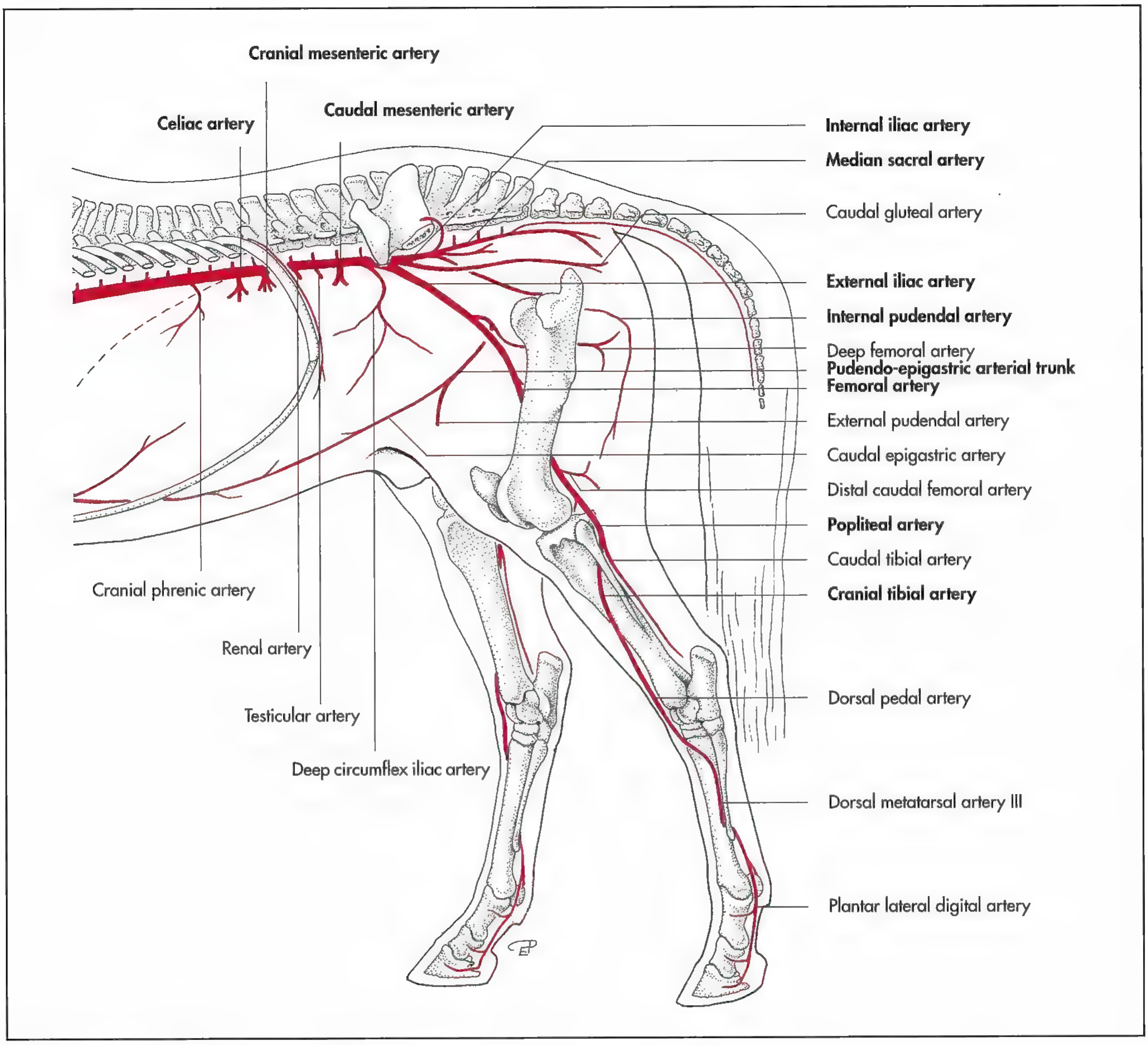

Fig. 12-36. Abdominal aorta and its larger branches of the horse, schematic.

- **Cranial mesenteric artery:**
  for the vascularised structures see chapter 7,
  - Caudal pancreaticoduodenal artery (a. pancreaticoduodenalis caudalis),
  - Jejunal arteries (aa. jejunales),
  - Ileocolic artery (a. ileocolica),
    - Cecal arteries (aa. caecales),
    - Ileal arteries (a. ilei),
    - Colic branch (ramus colicus),
    - Right colic artery (a. colica dextra),
    - Middle colic artery (a. colica media),
- **Renal arteries** (aa. renales),
- **Testicular / ovarian arteries** (aa. testiculares / aa. ovaricae),
- **Caudal mesenteric artery** (a. mesenterica caudalis),
  - Left colic artery (a. colica sinistra),
  - Cranial rectal artery (a. rectalis cranialis).

Termination of the abdominal aorta:

- **Right** and **left external iliac artery** (a. iliaca externa dextra et sinistra),

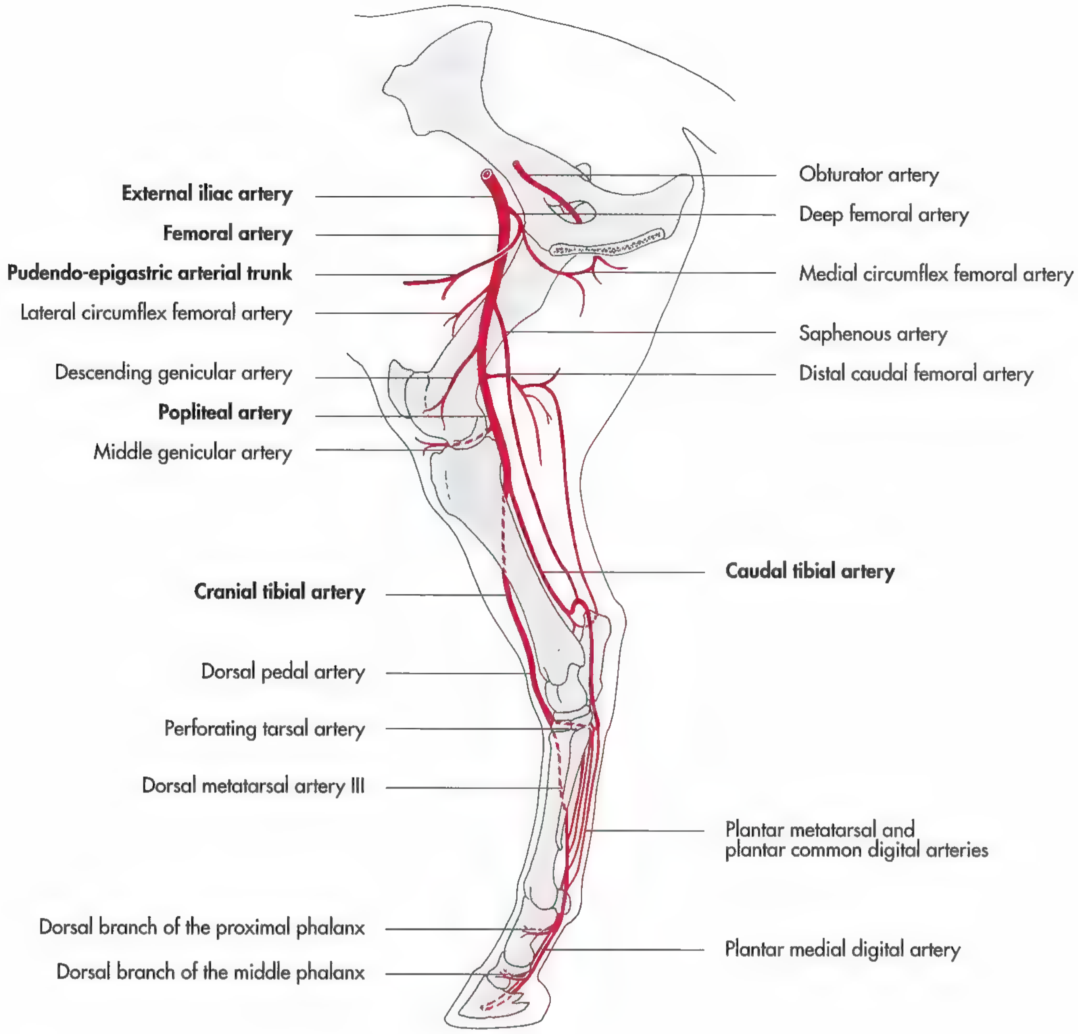

Fig. 12-37. Arteries of the pelvic limb of the horse, schematic (Dyce et al., 1991).

- **Right** and **left internal iliac artery** (a. iliaca interna dextra et sinistra),
- **Median sacral artery** (a. sacralis mediana).

External iliac artery

The external iliac artery is the **principal artery of the hindlimb.** After arising as one of the terminal branches of the aorta it runs along the body of the ilium, accompanied by the like-named vein and the genitofemoral nerve and detaches the deep circumflex iliac artery in large animals. In the mare, the first branch of the external iliac artery is the uterine artery (Fig. 11-38). In carnivores, the deep circumflex iliac artery arises directly from the aorta. Before entering the femoral canal, it sends branches into the muscles of the thigh and detaches the deep femoral artery, which is the common origin of the pudendoepigastric arterial trunk.

On leaving the abdomen the external iliac artery continues as the **femoral artery,** which passes through the femoral canal and is accompanied by the like-named vein and the saphenous nerve. The femoral canal is bound by the sartorius muscle cranially and the gracilis and pectineal muscle caudally (see chapter 2, Fig. 2-16). The femoral artery then passes between the adductor muscles on the medial side of the femur to reach the caudal aspect of the stifle, where it continues as the **popliteal artery.** The femoral artery has many branches to the muscles of the thigh.

The popliteal artery divides into **cranial** and **caudal tibial arteries** at the proximal part of the interosseous space. The larger cranial tibial artery passes distally on the craniolateral aspect of the tibia to reach the dorsal aspect of the hock as the **dorsal pedal artery.** It continues between the third and fourth

Fig. 12-38. Arteries of the pelvic cavity and the thigh of a dog, corrosion cast (courtesy of Prof. M. Navarro and A. Oliver, Barcelona).

metatarsal bones as the **dorsal metatarsal artery III,** the main vessel to the foot. It ends proximal to the fetlock by dividing into **medial** and **lateral digital arteries.**

Branches and vascularised structures of the **external iliac artery** (Fig. 12-36 and 37):

- **External iliac artery (a. iliaca externa):**
  - Uterine artery (A. uterina)(only mare),
  - Deep circumflex iliac artery (a. circumflexa ilium profunda),
  - Deep femoral artery (a. profunda femoris),
  - Pudendoepigastric arterial trunk (truncus pudendoepigastricus),
    - External pudendal artery (a. pudenda externa): Scrotum, mammary gland,
    - Caudal epigastric artery (a. epigastrica caudalis): abdominal muscles.
- **Femoral artery (a. femoralis):**
  - Lateral circumflex iliac artery (a. circumflexa femoris lateralis): muscles of the thigh,
  - Saphenous artery (a. saphena): Skin, muscles of the thigh and leg, digits),
  - Caudal femoral arteries (aa. caudales femoris): muscles of the thigh,
- **Popliteal artery** (a. poplitea):
  - Genicular arteries (aa. genus): caudal stifle joint,
  - Middle genicular artery (a. genus media): interior of stifle joint,
  - Caudal tibial artery (a. tibialis caudalis): caudal leg,
  - **Cranial tibial artery** (a. tibialis cranialis): caudolateral leg,
  - **Dorsal pedal artery** (a. dorsalis pedis): tarsal joints,
  - **Dorsal metatarsal artery III**
    - Lateral and medial plantar digital arteries: digit.

Several anastomoses are formed between the arteries of the hindlimb: the caudal epigastric artery anastomoses with the cranial epigastric vein, the deep femoral artery with the distal caudal femoral artery, the lateral circumflex femoral artery with the medial circumflex femoral artery, the descending genicular artery with the middle genicular artery.

Clinically important landmarks:

- Pulse: In the cat and dog the pulse can be taken at the femoral artery in its first part, where it has a superficial position on the inside of the thigh.
- Arterial blood sampling: The dorsal metatarsal artery, between the third and fourth metatarsal bones.

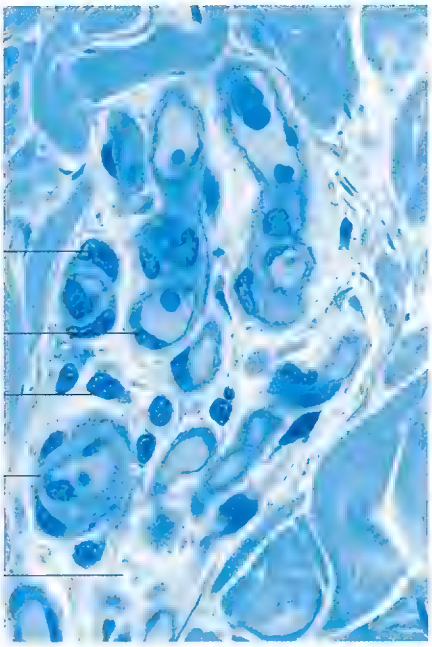

Fig. 12-39. Histological section of a capillary bed within the surrounding tissue.

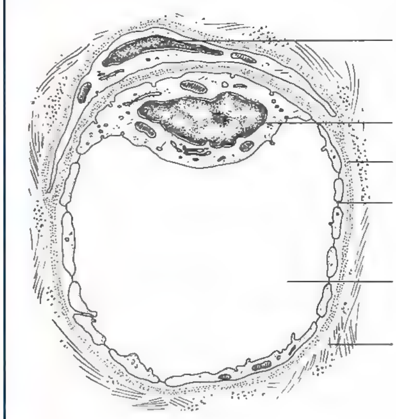

Fig. 12-40. Capillary, microscopic transverse section, schematic (Liebich, 2004).

Internal iliac artery

The internal iliac artery provides blood supply to the **pelvic viscera** and the **walls of the pelvic cavity,** including the lumbar muscles and the overlying muscles of the gluteal region. It is one of the terminal branches of the aorta and in the horse the **median sacral artery** can arise either from the left or the right internal iliac artery. The median sacral artery gives origin to **segmental branches** (Fig. 12-36). The internal iliac artery continues as the **internal pudendal artery,** that provides the blood supply for the **pelvic viscera** (Fig. 12-36 and 38). Its branches are differently named and disposed in the two sexes. It supplies the urinary bladder, ureters, urethra and the male and female genital organs.

Branches and supplied structures of the **internal iliac artery:**

- **Internal iliac artery** (a. iliaca interna),
  - Median sacral artery (a. sacralis mediana),
  - Caudal gluteal artery (a. glutea caudalis),
  - Obturator artery (a. obturatoria),
  - Cranial gluteal artery (a. glutea cranialis): gluteal muscles
  - Iliolumbar artery (a. iliolumbalis): deep lumbar muscles,
- **Internal pudendal artery** (a. pudenda interna),
  - Umbilical artery (a. umbilicalis):
  - Uterine artery (a. uterina) (without mare), remnant of fetal blood supply,
  - Vaginal artery (a. vaginalis): urinary bladder, urethra, uterus, vagina, rectum / prostatic artery (a. prostatica): urinary bladder, urethra, accessory genital glands, rectum,
  - Caudal rectal artery (a. rectalis caudalis): rectum and anus,
  - Ventral perineal artery (a. perinealis ventralis): perineum,
  - Vestibular artery (a. vestibularis): vestibule/artery of the penis,
  - Artery of bulb of vestibule (a. bulbi vestibuli)
  - Dorsal artery of the penis (a. dorsalis penis).

Capillaries

Capillaries are the minute connections between the smallest arteries and the smallest veins within the tissues, where molecular exchange takes place. To provide ideal conditions for the exchange of molecules between the blood and the tissues and vice versa, the velocity of the blood is reduced to about 0.3 mm/sec, compared to 320 mm/sec within the aorta. Blood pressure is also largely reduced. The **lumen** of a capillary measures about 5–15 µm in diameter. They are arranged in a three dimensional network, forming a so-called **capillary bed.** Capillaries are present in all tissues other than the cornea, lens, enamel and cartilage.

The capillary wall is composed of a continuous **endothelium** and an underlying basilar membrane (Fig. 12-39 and 40). However, minute pores are present in so-called **fenestrated capillaries,** which are typical of some organs, e.g. intestinal villi and renal glomeruli. **Sinusoids** are a special type of capillaries found in certain organs, including the liver, the spleen and the red bone marrow. They are wider (about 40 µm), have a generous fenestration and an incomplete basal membrane.

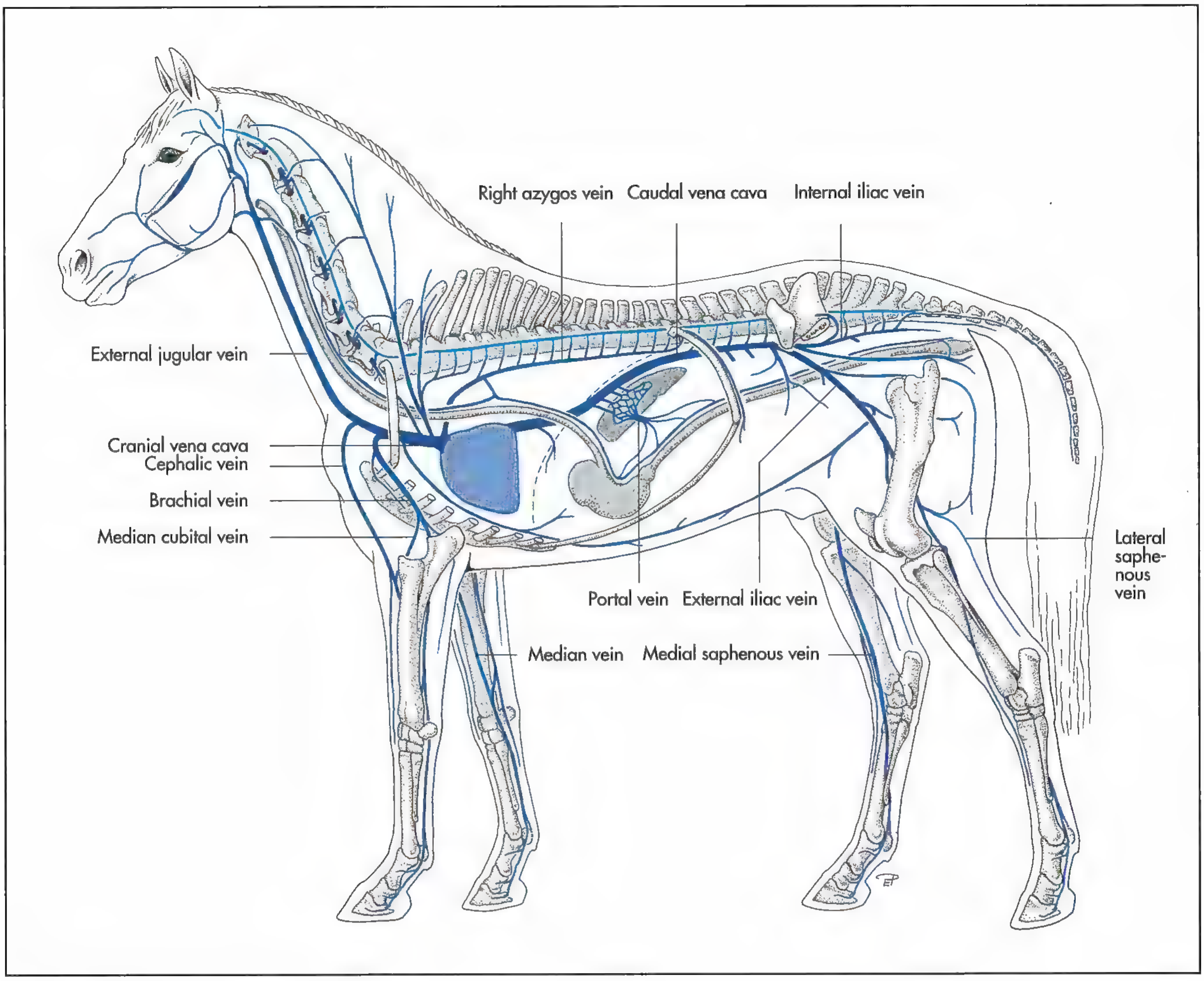

Fig. 12-41. Venous system of the horse, schematic.

Precapillary sphincters are located at the junction between the arterioles and the capillaries to control blood-flow into the capillary bed. Some veins, e.g. in the genital organs, also have sphincters, which are able to control blood flow from the preceding capillary bed.

Precapillary anastomoses between arteries and veins are present in some body regions and enable the blood to bypass the capillary bed, e.g. the digital arteries of the hoof.

Most capillary beds are supplied by more than one artery. However, there are so-called end-arteries that do not form anastomoses. Thus obliteration of an end-artery can not be compensated for and leads to local ischaemia and necrosis. Such arteries are commonly found in the brain, the heart, the retina and the kidneys. Therefore these organs are most likely to become diseased due to infarction.

The **density of the capillary network** varies with the tissue: there is an especially high density in the myocardium, the grey matter of the central nervous system and the endocrine glands. Some capillary beds undergo cyclic changes, e.g. in the ovaries.

Veins (venae)

In general veins (Greek phleb, Latin vena) return blood from the periphery to the heart, while arteries lead blood from the heart to the tissues. Most textbooks use a retrograde description of veins, where the passage of veins is described against the direction of the blood stream.

This leads to misunderstandings with regards to the effect of intravenous injections, orientation of the valves, arteriovenous anastomoses and blood flow. In fact, veins have a capillary bed from which they arise as **small veins** (venules), that become confluent to form **larger veins,** that finally drain into the **right atrium of the heart.** Veins of the **pulmonary circulation** transport oxygenated blood from the lung to the left atrium of the heart.

Some textbooks reduce venous function to drainage of tissues only. However, several organs, e.g. the liver and the hypophysis receive venous blood supply. Therefore veins do not only remove metabolites from the tissues, but also supply those tissues with the metabolites and hormones.

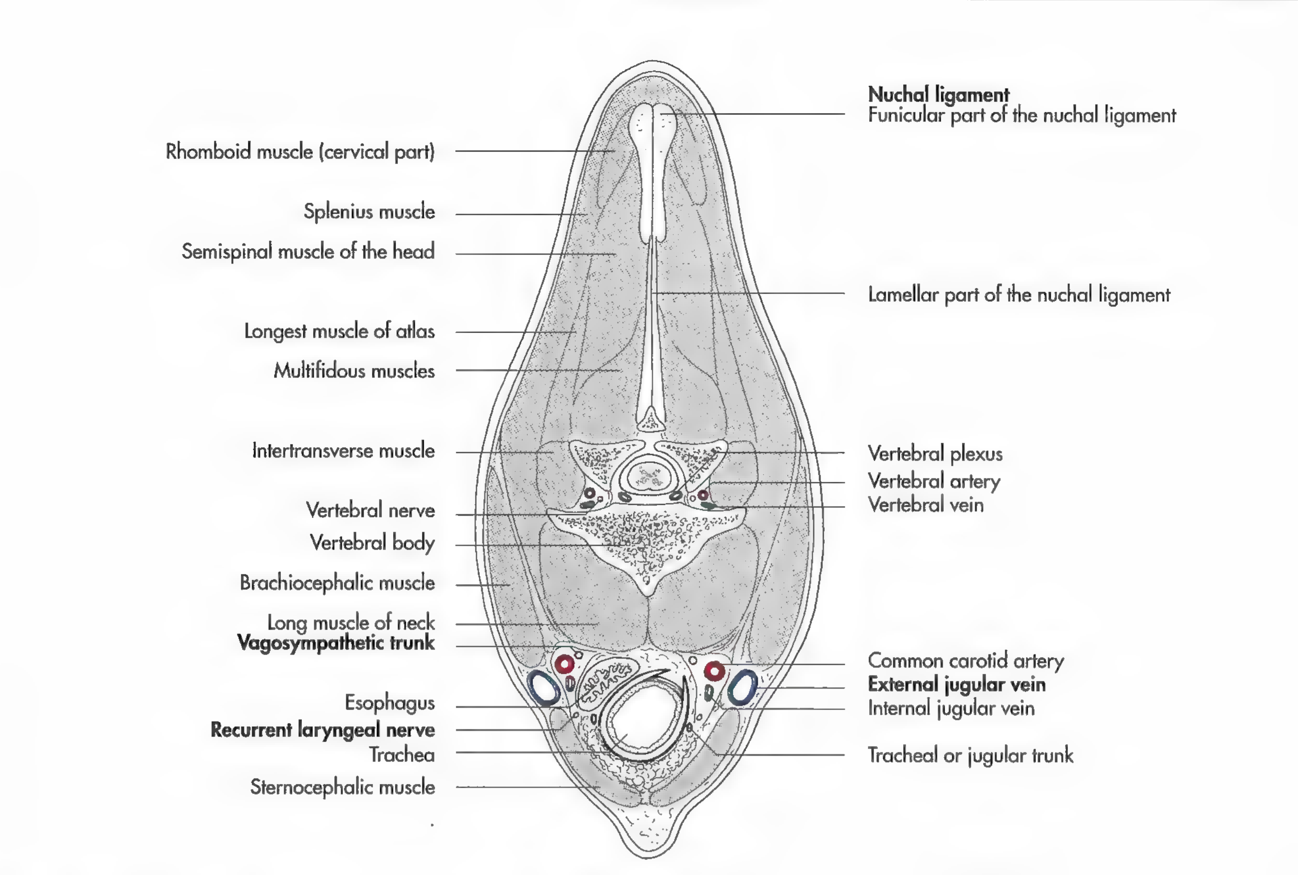

Fig. 12-42. Transverse section of the neck of the ox, caudal aspect, schematic.

Most veins accompany the corresponding arteries and are said to be satellites to the mostly like-named arteries.

The **composition of venous blood** largely depends on the tributary territory. Venous blood from the intestines is rich in nutritious molecules, blood from the spleen has a high number of white blood cells and blood from endocrine glands have a high hormone level, whereas venous blood from the kidneys has a low content of metabolites. Veins also play an important role in the **regulation of body temperature,** e.g. veins from the liver and muscles carry blood of a higher temperature.

Veins have a **similar construction to arteries,** though thinner walled, which is mainly due to the weak middle tunic (Fig. 12-15). The inner tunic forms **valves,** which ensure unidirectional flow towards the heart and prevent retrograde flow of blood, when circulation stagnates. Valves are not present in the veins of the cranial cavity or the vertebral canal, these veins are referred to as **venous sinuses.** Some veins of the cranial cavity do not have a wall, but pass in a diverticulum of the dura mater, which is lined by an endothelium.

Veins of the limbs often pass in a common soft tissue sheath, together with an artery. Thus pulsation of the artery enhances venous blood movement toward the heart, which is assisted by an increase in thickness of the tunica media in the distal veins.

Portal veins are veins, which flow between two capillary beds e.g. the portal system of the liver and the pituitary gland.

Cranial vena cava (v. cava cranialis) and its tributaries

The tributary branches of the cranial vena cava drain the head, neck, thorax and the thoracic limbs (Fig. 12-41 and 43). The **unpaired cranial vena cava** is formed, at the level of the thoracic inlet, by the convergence of the **jugular veins.** It is then joined by the **right** and **left subclavian veins,** the tributaries of which are satellites to the corresponding arteries and the bronchoesophageal vein. In the horse, dog and cat, it is also joined by the right azygous vein near to its termination.

The root of the cranial vena cava receives the **lymph** from the **thoracic duct,** which conveys the lymph from the body tissues into the blood circulation.

The cranial vena cava passes through the cranial mediastinum to the right of the brachiocephalic trunk and opens into the right atrium.

Veins of the head and neck

The veins of the head can be divided into veins that lie within the cranial cavity and veins that are outside the cranial cavity. The **valveless veins** within the cranial cavity are described in chapter 14, "Nervous System". The veins of the head outside the cranial cavity usually run as satellites to the corresponding arteries. In the horse, tributaries of the facial vein are locally dilated to form **three venous sinuses** running along

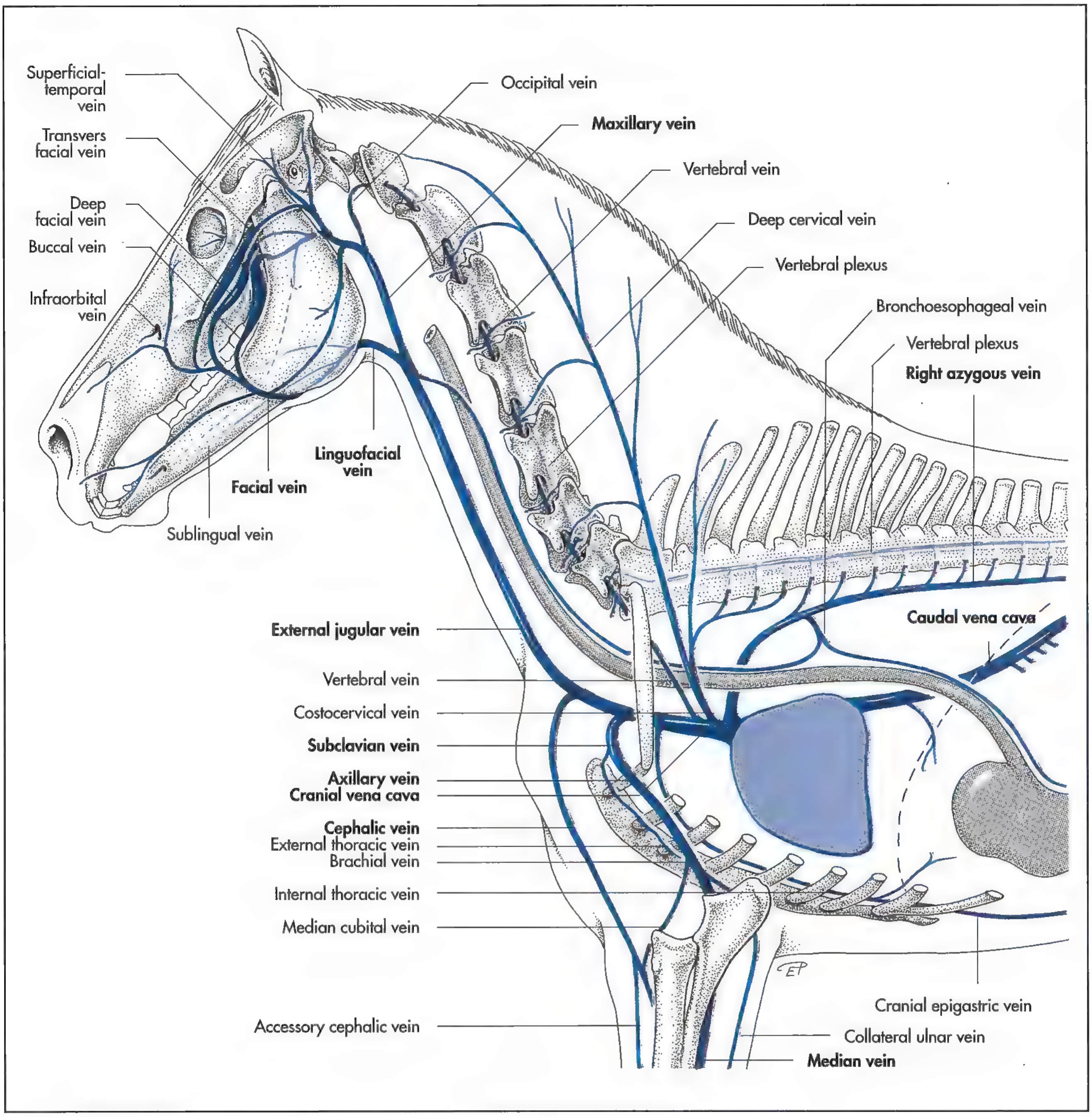

Fig. 12-43. Larger veins of the head, neck and the thoracic limbs and the tributaries to the cranial vena cava of the horse, simplified, schematic.

the facial crest and below the masticatory musculature. They promote blood flow toward the heart during mastication. Blood can be sampled from one of these sinuses by drawing a virtual line from the nasal canthus of the eye to the facial crest and advancing a needle off its ventral rim, advancing the needle in a medial direction.

The **external jugular vein** is formed near the angle of the jaw by the union of the linguofacial and the maxillary veins (Fig. 12-43). It runs along the neck, occupying the **jugular groove** (sulcus jugularis) between the brachiocephalic muscle dorsally and the sternocephalic muscle ventrally. In the cranial and middle third of the neck it has a subcutaneous position. It is therefore the first choice for **blood sampling** and **intravenous injection** in most animals. In the dog, the left and right external jugular vein communicate via the hyoid venous arch, an unpaired vein, that connects the right and left lingual veins ventral to the basihyoid bone.

In all domestic mammals other than the horse and the goat, there are **two pairs of jugular veins.** In addition to the external jugular vein, these animals have a **(deep) internal jugular vein,** which runs between the common carotid artery and the trachea to unite with the **external jugular vein** at the base of the neck.

Fig. 12-44. Lateral saphenous vein of a dog, lateral aspect.

Azygous vein (v. azygos)

The azygous vein is formed by the union of the **first two lumbar veins** and passes through the **aortic hiatus** into the thorax, where it receives blood from the intercostal veins of the caudal and middle thoracic region. Although right and left azygous veins are present in the embryo, the pattern is later commonly simplified: in the horse, dog and cat the right azygous vein persists (Fig. 12-41 and 43), in the pig the left or occasionally both persist, in ruminants both veins are usually present.

The **right azygous vein** opens into the terminal part of the **cranial vena cava,** the **left azygous** drains directly into the **coronary sinus.** The azygous system is of special importance in draining the plexus within the vertebral canal.

Veins of the thoracic limb

The veins of the thoracic limb begin with **terminal venous networks** (arcus terminalis) within the digits, the corium and the hoof cartilages. These networks become confluent to form the following veins in distal to proximal order:

- Medial and lateral digital palmar veins (vv. digitales palmares medialis/lateralis),
- Metacarpal veins (vv. metacarpeae),
- Median vein (v. mediana),
  – Accessory cephalic vein (v. cephalica accessoria),
  – Cephalic vein (v. cephalica),
- Brachial vein (v. brachialis),
- Median cubital vein (v. mediana cubiti),
- Axillary vein (v. axillaris),
- Subclavian vein (v. subclavia),
- External jugular vein (v. jugularis externa) and
- Cranial vena cava (v. cava cranialis).

Most veins of the forelimb are satellites, though often duplicated, where they accompany the larger arteries. The **tunica media of the wall** is increased in thickness in the veins of the distal limb in response to elevated venous pressure. These veins are also closely related to arteries to facilitate retrograde blood flow. The tributaries of the axillary vein form the **deep venous system** of the limb, while the **cephalic vein** is the only large superficial vein. It is formed by the union of the deep **metacarpal veins** on the medial aspect of the carpus and is joined by the accessory cephalic vein that arises from a venous network on the dorsal aspect of the carpus, in the middle of the forearm. It continues proximally in a subcutaneous position to join the **external jugular vein** in the lower part of the neck.

At the level of the elbow and shoulder joint, it anastomoses with the **median cubital vein.** The **cephalic vein** is the most popular choice for **venous injection** in dogs and cats. It follows the **cranial border of the forearm,** where it can be palpated, when raised by exerting pressure over the elbow.

Veins of the pelvic limb

Corresponding to the forelimb, the veins of the pelvic limb (Fig. 12-45) originate in venous networks in the terminal part of the digit **(arcus terminalis).** These networks become confluent to form the following veins in distal to proximal order:

- Medial and lateral plantar digital veins (vv. digitales plantares medialis et lateralis),
- Metatarsal veins (vv. metatarseae),
- Dorsal pedal vein (v. dors. pedis),
- Cranial tibial vein (v. tibialis cranialis),
  – Medial saphenous vein (v. saphena medialis),
  – Lateral saphenous vein (v. saphena lateralis),
- Popliteal vein (v. poplitea),
- Femoral vein (v. femoralis),

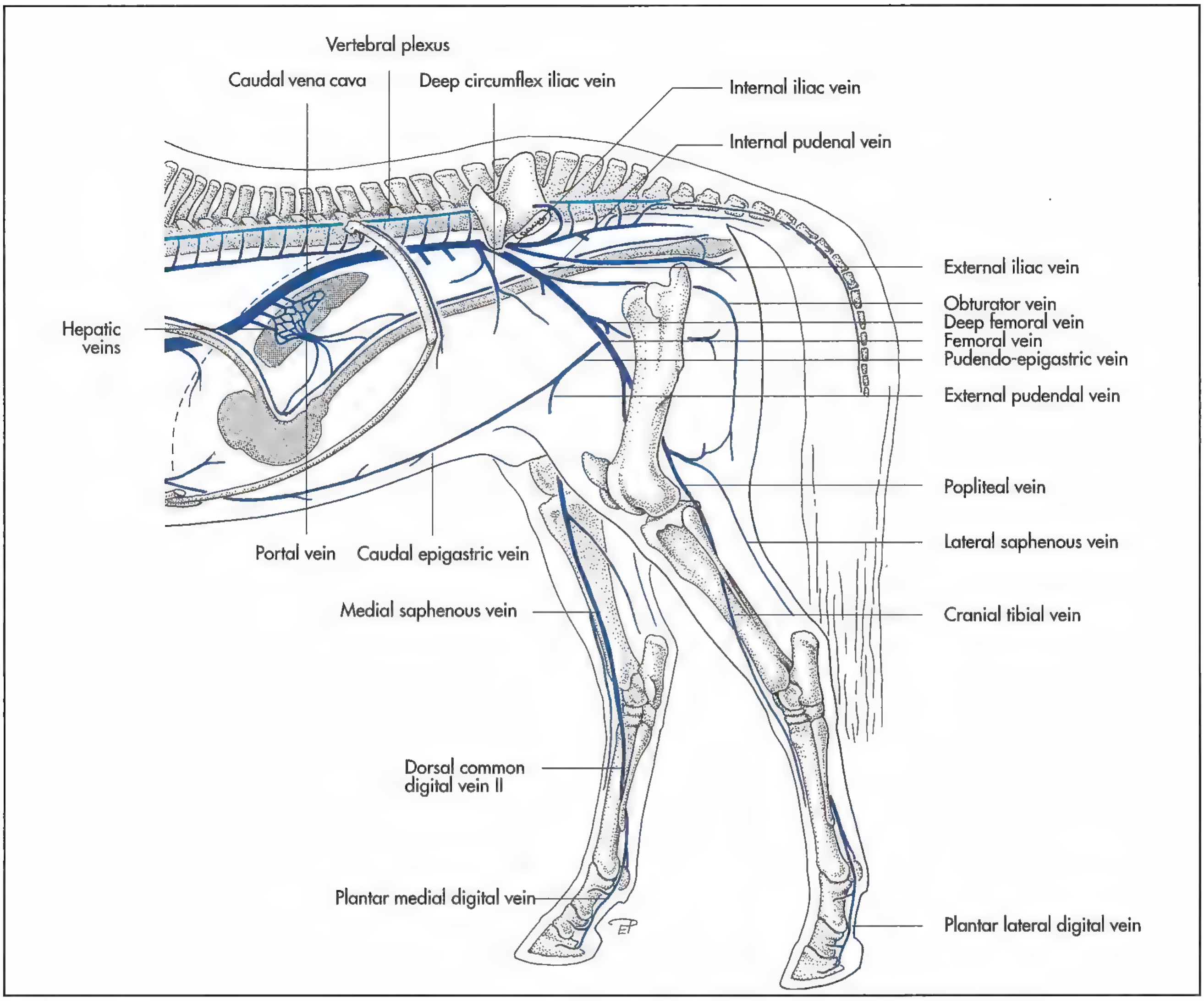

Fig. 12-45. Larger veins of the pelvic limb and the tributaries to the caudal vena cava of the horse, schematic.

- External iliac vein (v. iliaca externa),
- Internal iliac vein (v. iliaca interna) and
- Caudal vena cava (v. cava caudalis).

The deep veins are largely satellites to the arteries. As in the forelimb, certain superficial veins, including the **medial** and **lateral saphenous veins** run alone (Fig. 12-44 and 45). Each saphenous vein originates from a cranial and caudal branch from the tarsus, and unites in the middle of the leg. At the level of the tarsus, they communicate with the deep **metatarsal veins.** Within the leg, the saphenous veins run medially and laterally between the calcanean tendon and the caudal muscle mass. The medial vein is the larger of the two in all domestic animals other than the dog and crosses the medial aspect of the thigh to open into the **femoral vein.** The lateral vein joins the deep femoral vein at the stifle.

In the cat the medial saphenous vein can be used for intravenous injections, especially during anaesthesia. In the dog the lateral saphenous vein can be used for venipuncture above the tarsus.

Caudal vena cava (v. cava caudalis)

The caudal vena cava begins on the roof of the abdomen at the level of the **last lumbar vertebrae** by convergence of the **median sacral vein** and the **common iliac veins,** which in turn are formed by the union of the external and internal iliac arteries (Fig. 12-45). The **external iliac veins** and the bulk of their tributaries are satellites to arteries and drain the hindlegs. The **internal iliac veins** drain the pelvic walls and much of the pelvic viscera. It communicates with the vertebral plexus and the venous system of the intestines through the median sacral vein. The **caudal vena cava** passes cranially along the roof of the abdomen to the **right of the aorta.** In its intra-abdominal course, it is joined by the renal veins and the segmental veins of the lumbar spine before it continues between the liver. Here it is joined by the hepatic veins, and the receiving the veins of the diaphragm. It enters the thorax by passing through the diaphragm at the **caval foramen** and pursues a course within the free edge of a special pleural fold, the **plica venae cavae,** on the right side of the caudal mediastinum, accompanied by the phrenic nerve. It ends by opening into

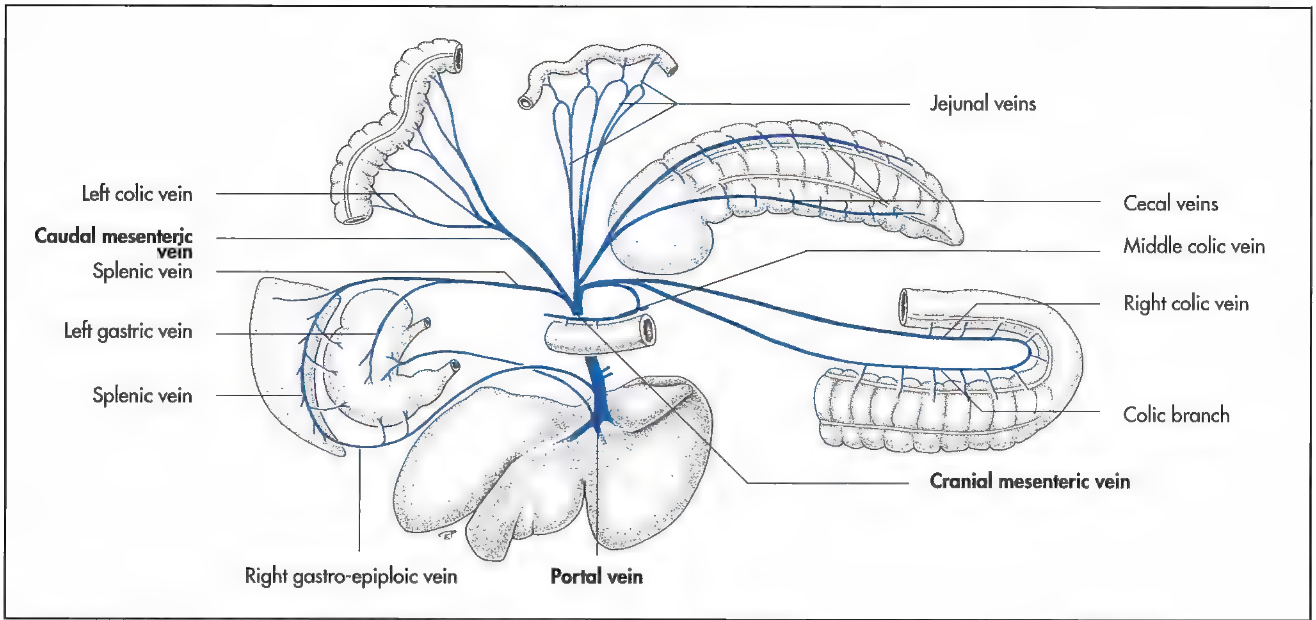

Fig. 12-46. Hepatic portal system of the horse (Ghetie, 1955).

the **right atrium.** Veins from the genital organs and the adrenal glands convey hormones to the cranial vena cava, through which they are distributed in the body without having to pass the liver first.

Space occupying lesions, such as tumours, can cause obstructions within the venous system, that lead to blood stagnation. The system reacts by using alternative blood routes. One of these alternative routes is provided by the valveless venous system of the vertebral column.

On its cranial end it communicates with the veins of the head and neck and thus with the **cranial vena cava,** on its caudal end it communicates with the **caudal vena cava** through the segmental nerves of the spine. Additional collateral pathways of venous drainage are provided by veins along the intestinal tract. Caudal tributaries of the caudal vena cava, that drain the rectum anastomose with tributaries of the **portal vein,** which in turn has tributaries, that anastomose with the oesophageal vein and again an indirect connection between the cranial and caudal vena cava is formed. This provides an alternative outlet from the portal drainage territory, which is used when the intrahepatic circulation is impaired as for example by cirrhosis. A **third venous circle** is formed ventrally by the anastomoses of the epigastric veins.

Portal vein (v. portae)

The portal vein collects blood from **all unpaired organs** within the abdominal cavity and transports the blood to the liver. (Fig. 12-46). The portal vein and its tributaries form a **portal system.** It arises from capillaries in the viscera, which become confluent to form the cranial and caudal mesenteric and the splenic veins, the three root vessels of the portal vein. Within the liver the portal vein divides to finally form **liver sinusoids,** blood-filled cavities, enclosed by sheets of hepatic cells. Sinusoid blood is collected in the **central vein** of each hepatic lobule, which constitute the beginning of the **efferent venous system** of the liver. Adjacent central veins fuse to form the **interlobular veins,** which unite with each other to finally form the **hepatic veins,** which empty in the caudal vena cava. Nutritional supply to the liver is provided by the hepatic arteries and the hepatocytes are bathed by **mixed blood** from the **portal vein** and the **hepatic arteries,** so that they receive nutrition from both. Branches of the portal vein and the hepatic veins can be assessed ultrasonographically or with contrast radiography. The portal vein brings the functional blood to the liver: it receives nutritional molecules from the intestines and hormones from the pancreas.

In the foetus the **umbilical vein** from the placenta enters the liver and is shunted into the posterior vena cava through the **ductus venosus.** Shortly after birth this duct becomes obliterated. However, in some animals, most commonly in dogs, this duct persists, forming a direct connection between the portal vein and the caudal vena cava, that requires surgical intervention.

Arteries and veins of the digit

The digits receive their main blood supply on their palmar (plantar) aspect, where the palmar artery splits into several digital arteries according to the number of digits. The paw of dogs and cats receives additional blood supply from dorsal digital arteries. Within the distal phalanges the **palmar (plantar) digital arteries anastomose** with each other, thus forming the **terminal arches.** In the middle of each phalanx, the arteries detach branches, which surround the phalanx.

The veins of the digits are largely satellites of the arteries, although there are veins on the dorsal aspect of the digit.

Clinical terms related to the cardiovascular system: Arteritis, angiography, persistent ductus arteriosus, thrombophlebitis, angiopathy, pericarditis, endocarditis, arteriosclerosis, vasculitis, coronary infarct.

13 Immune system and lymphatic organs (organa lymphopoetica)

H. E. König and H.-G. Liebich

The immune system provides **specific** and **non-specific defence mechanisms** to protect the body against environmental influences. It is therefore vital in maintaining the animal's health. The immune system can be divided into cellular and vascular components. The **cellular component** includes the lymphatic tissue found as single cells, which are diffusely dispersed within tissues, as aggregations of lymphatic cells (tonsils) or in lymphatic organs (thymus, lymph nodes and spleen). **Circulating components** include lymphocytes, monocytes, and plasma cells, which are found in lymphatic organs, blood, tissue spaces and the lymph stream. The lymphatic vascular system includes lymph capillaries, lymph vessels and lymph collecting ducts.

The thymus plays an essential role in the development of the lymphatic cellular components, by controlling growth of the lymphatic organs in immature animals.

Lymphocytes are the predominant cell type of the immune system, and can be divided into **B-** and **T- lymphocytes.** They are formed within the bone marrow and lymphatic organs and are distributed within the lymphatics and in blood. Their cell surface is marked by specific receptors, with which they are able to recognise and bind molecules and trigger a chain of reactions, which leads to a **specific immune response.**

Macrophages are part of the **mononuclear phagocytosis system (MPS),** which is responsible for the non-specific immune response. This system also comprises the alveolar macrophages of the lung, Langerhans cells of the skin, mesoglia in the central nervous system, and the endothelium of the liver, spleen and bone marrow sinusoids. Formerly the MPS was referred to as reticuloendothelial system (RES).

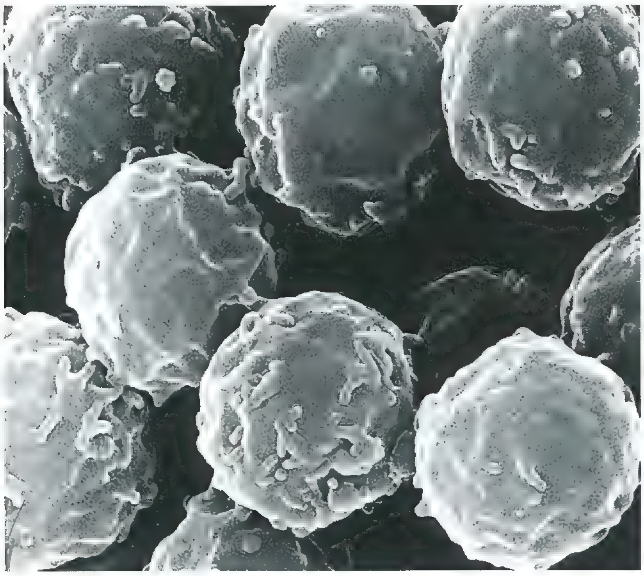

Fig. 13-1. Scanning electronmicroscopic image (SEM) of lymphocytes.

Lymph vessels (vasa lymphatica)

During the circulation of blood from arteries to veins, proteins are able to pass through the capillary walls into the interstitial fluid spaces. This clear, colourless transudate is called lymph and is taken up by the blind-ending lymphatic capillaries. The lymphatic capillaries form plexuses within most body tissues from which larger lymph vessels take their origin. Lymph vessels open into lymph ducts, which eventually drain into the jugular vein or the cranial vena cava. Lymph vessels are interrupted by lymph nodes, which function as filters and germinative centres for lymphocytes. No lymph vessels are found within the central nervous system.

The **lymph capillaries** are lined by a continuous single-layered endothelium with an underlying incomplete basal membrane. Unlike the lymph vessels, they have **no valves.** Openings appear, at intervals, between adjacent endothelial cells and allow fluids or emulsified fats (e.g. from the intestines) to pass through the wall into the lumen of the capillaries.

The **lymphatic vessels** have thinner walls than those of comparably sized veins, but contain more valves. Contractions of the relatively thin middle muscular tunic are responsible for flow of lymph towards the thoracic duct. The high number of successive valves gives the lymph vessels their characteristic appearance, they resembling a string of beads, when distended. This appearance can be demonstrated in the live animal with the use of contrast radiography.

Lymph vessels that transport the lymph from the capillary region to a lymph node are termed **afferent lymph vessels. Efferent lymph vessels** leave the lymph node, carrying lymph that is filtered and enriched with lymphocytes.

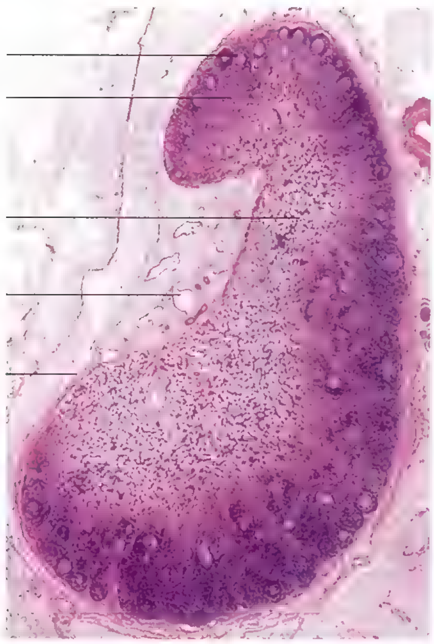

Fig. 13-2. Histological section of a lymph node of a sheep.

Fig. 13-3. Histological section of a lymph node of a pig.

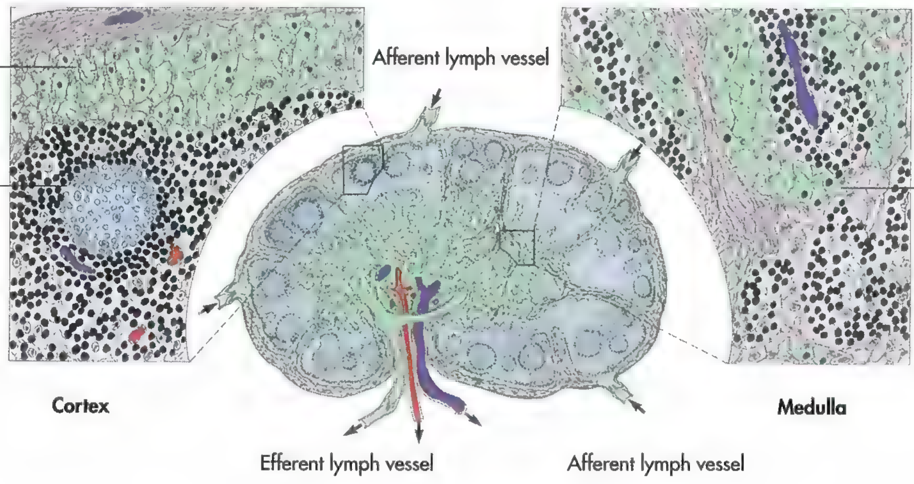

Fig. 13-4. Internal structure of the bovine lymph node, schematic (Liebich, 2004).

Lymph nodes (lymphonodus, nodus lymphaticus)

Lymph nodes are firm, smooth-surfaced, generally ovoid or bean-shaped with a large convex surface and a smaller concave area, the hilus.

Internally the lymph node is divided into a **cortex** and a **medulla.** The cortex contains the **germinal centres** in which lymphocytes are continually produced. The medulla consists of **anastomosing cords** of lymphocytes (Fig. 13-4). A soft tissue capsule, from which septa and trabeculae extend into the organ to forming an internal framework (Fig. 13-2 to 3), encloses each lymph node. Afferent lymph vessels open into

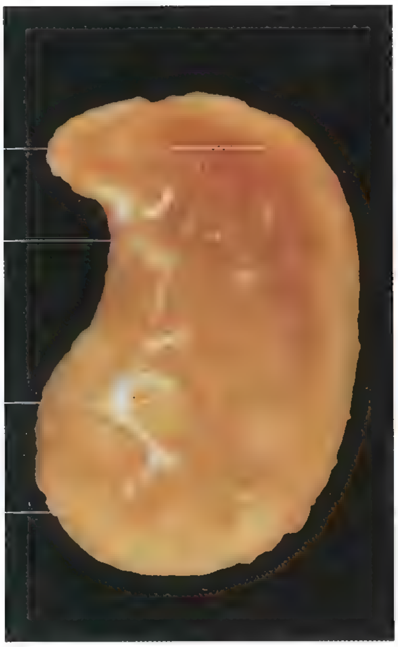

Fig. 13-5. Lymph node of a pig, transverse section (courtesy of PD Dr. S. Reese, Munich).

Fig. 13-6. Lymph node of a pig (courtesy of PD Dr. S. Reese, Munich).

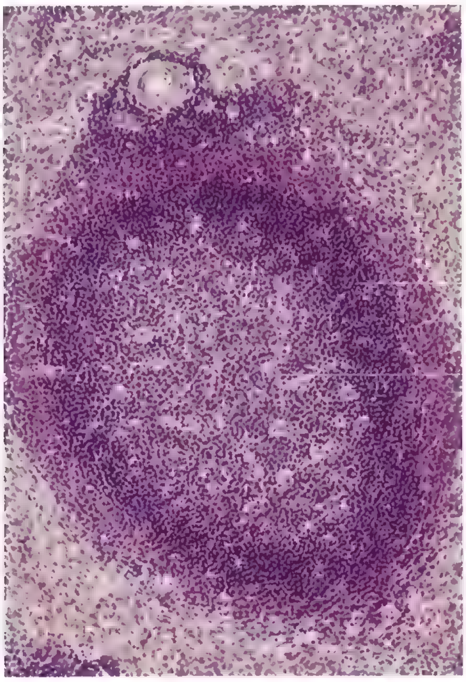

Fig. 13-7. Histological section of a lymph follicle.

the **subcapsular sinus** (sinus marginalis). Branches from the subcapsular sinus form a **medullary sinus,** close to the hilus, where the efferent lymph vessels emerge. In the pig, this organisational order is reversed: afferent vessels enter the lymph node at the hilus and efferent vessels leave the lymph node via the subscapsular sinus. Lymph nodes are well vascularised by blood vessels that enter the organ at the hilus.

Each lymph node is responsible for draining a certain region, its **tributary territory.** Groups of neighbouring lymph nodes constitute **lymph centres** (lymphocentrum, lc.). There are species-specific differences in the lymph centres: the lymph centres of carnivores and ruminants contain fewer, but individually large lymph nodes, while those of pigs and horses contain a large number of relatively small lymph nodes.

All lymph, with very few, disputed exceptions, passes through at least one lymph node on its passage from the tissues to the blood stream. Within the lymph nodes most particulate matter, including microorganisms and tumour cells, are removed and destroyed. Thus the lymph node provides a barrier to the spread of infection and tumours. Swelling of a lymph node usually indicates the existence of a disease process in its tributary territory.

Knowledge of the location, the accessibility and the tributary territory is essential for any veterinarian, especially surgeons, pathologists and veterinarians engaged in meat inspection.

Lymph nodes of the head

The lymph nodes of the head (Fig. 13-8 and 9) are grouped into the following lymph centres:

- Parotid lymph centre (lc. parotideum),
- Mandibular lymph centre (lc. mandibulare),
- Retropharyngeal lymph centre (lc. retropharyngeum).

Parotid lymph centre

The parotid lymph centre consists of one or more parotid lymph nodes at the base of the ear, close to the temporoman-

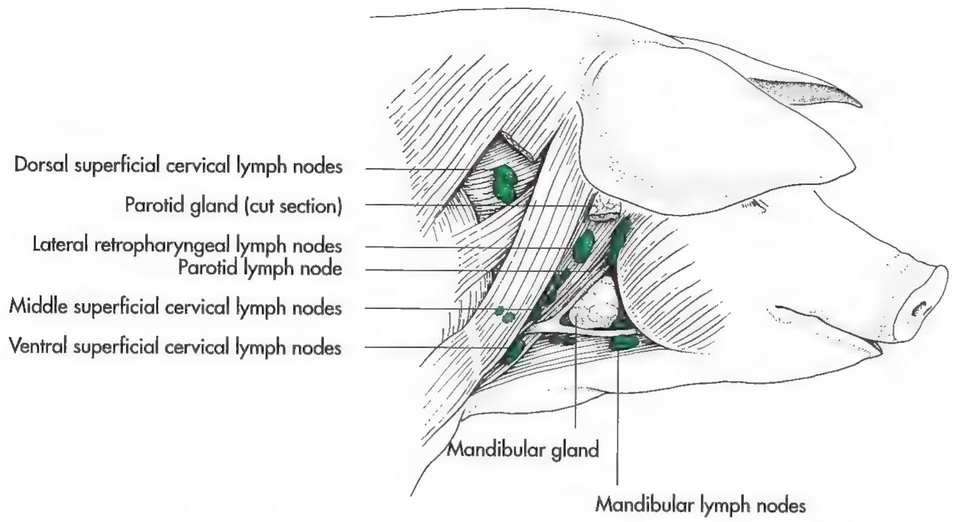

Fig. 13-8. Lymph nodes of the head and the cranial part of the neck of the pig, schematic (Najbrt, 1982).

dibular joint, covered by the parotid gland or the masseter muscle. The afferent lymphatics drain the dorsal half of the head, the orbit and the masticatory muscles (Fig. 13-8 and 12).

Mandibular lymph centre

The mandibular lymph centre comprises a number of lymph nodes located between the hemimandibles, in close proximity to the greater sublingual salivary gland and the mandibular salivary gland. They can be easily identified on palpation. The afferent lymphatics to the mandibular lymph centre drain the oral cavity, including the tongue and teeth, the salivary glands, the intermandibular space and the masticatory muscles (Fig. 13-8, 9 and 12).

Retropharyngeal lymph centre

The retropharyngeal lymph centre is divided into a medial and a lateral group (lnn. retropharyngei mediales et laterales). Their afferent lymph vessels drain the deep parts of the head, including the pharynx, larynx, the cranial part of the trachea and the esophagus (Fig. 13-8, 9 and 12).

In the horse the lateral retropharyngeal lymph node drains from the guttural pouch. All lymph from the head passes through the medial retropharyngeal lymph nodes before it drains into the tracheal (jugular) trunk.

Lymph nodes of neck

The lymph nodes of the neck are organised in two groups:

- Superficial cervical lymph centre (lc. cervicale superficiale),
- Deep cervical lymph centre (lc. cervicale profundum).

Superficial cervical lymph centre

The superficial cervical lymph centre is located cranial to the shoulder joint, covered by the brachiocephalic and the omotransversarius muscles. The lymph nodes of the superficial cervical lymph centre include the dorsal, middle and ventral superficial cervical lymph nodes, with species specific variations.

These lymph nodes have a relatively extended tributary territory, including the skin and underlying structures of the cervical region, the thorax and the proximal part of the thoracic limb (Fig. 13-8 and 12). Efferent lymph vessels of these lymph nodes pass to the caudal **deep cervical lymph nodes.**

Deep cervical lymph centre

The deep cervical lymph centre comprises several groups of lymph nodes, which are located along the trachea (Fig. 13-9 and 12). They consist of cranial, middle and caudal deep cervical lymph nodes. There is a great variation in distribution of these lymph nodes and the middle one may be absent in some species. The tributary territory of this lymph centre includes the deep structures of the cervical region, including the esophagus, the trachea, the thymus and the thyroid gland.

The efferent lymph vessels from the deep cervical lymph nodes join the lymphatic duct, that passes caudally along the trachea, parallel to the common carotid artery to open into the cranial vena cava or, as it is sometimes seen in the left lymphatic duct, into the **thoracic duct.**

Lymph nodes of the thoracic limb

Lymph from the superficial and proximal parts of the forelimb drains to the superficial cervical lymph centre, lymph from the rest of the limb drain in to the axillary lymph centre (Fig. 13-12).

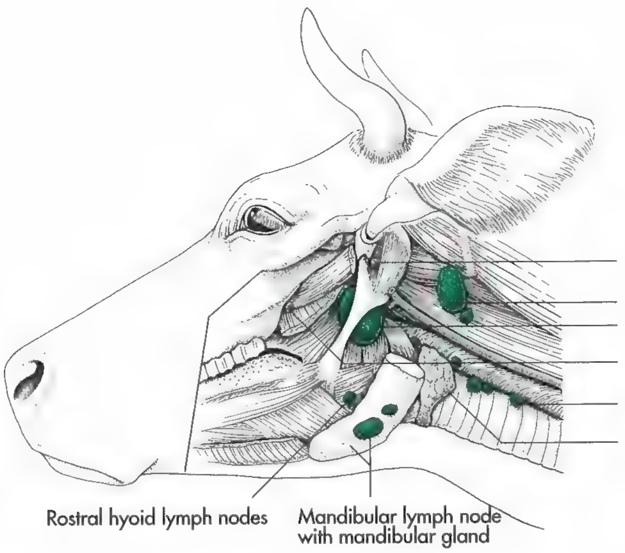

Fig. 13-9. Deep lymph nodes of the head and the cranial part of the neck of the ox, schematic (Najbrt, 1982).

Axillary lymph centre

The axillary lymph centre lies within the axilla, medial to the shoulder joint, where the axillary artery bifurcates to form the subscapular and the brachial artery. In addition to the **proper axillary lymph node** (ln. axillaris proprius), there may be an **accessory axillary lymph node,** (ln. axillaris accessorius) caudal to it and the **lymph node of the first rib** (ln. axillaris primae costae) cranial to it. In the horse and the sheep a more distal group may be located on the medial aspect of the **elbow joint** (lnn. cubiti).

The **axillary centre** drains the deeper structures of the entire limb and the superficial structures of the distal part of the limb. Its tributary territory also extends on the lateroventral aspect of the thorax, including the cranial mammary glands located in this region. This has to be considered, when surgical removal of mammary tumours is performed.

The efferent lymph vessels of the axillary lymph centre open into the terminal part of the lymphatic duct or directly into the veins at the thoracic inlet.

Lymph nodes of the thorax

The **walls of the thorax** are drained by the:
- Dorsal thoracic lymph centre (lc. thoracicum dorsale),
- Ventral thoracic lymph centre (lc. thoracicum ventrale).

The **organs within the thoracic cavity** are drained by the:
- Mediastinal lymph centre (lc. mediastinale),
- Bronchial lymph centre (lc. bronchiale),
- Dorsal thoracic lymph centre (lc. thoracicum dorsale) and
- Ventral thoracic lymph centre (lc. thoracicum ventrale).

Dorsal thoracic lymph centre

The dorsal thoracic lymph centre comprises two groups of lymph nodes, the **intercostal lymph nodes** (lnn. intercostales) and the **thoracic aortic lymph nodes** (lnn. thoracici aortici) (Fig. 13-10 and 12). As indicated by their name the intercostal lymph nodes are located within the upper part of some of the intercostal spaces and those of the thoracic aortic are dispersed along the aorta. They are inconsistent in number between species.

Ruminants often have **hemal nodes** in this region. Hemal nodes (lymphonodus hemalis) have a similar architecture to lymph nodes, but differ from lymph nodes in that their sinuses do not contain lymph, but **blood** and are connected to blood vessels, instead of lymph vessels.

The dorsal thoracic lymph centre drains the roof of the thorax and sends its efferent vessels to the thoracic duct.

Ventral thoracic lymph centre

The lymph nodes of the ventral thoracic lymph centre are located dorsal to the sternum and lateral to the transverse thoracic muscle. They are grouped in a cranial set in all domestic species with ruminants and some cats having a second caudal set of ventral thoracic lymph nodes (Fig. 13-10 and 12).

The ventral thoracic lymph centre drains the ventral part of the thoracic wall and it sends its efferent lymph vessels either directly to the thoracic duct or to the mediastinal lymph nodes.

Mediastinal lymph centre

The mediastinal lymph centre comprises cranial, middle and caudal mediastinal lymph nodes, which are located in the like-named part of the mediastinum. The caudal set is miss-

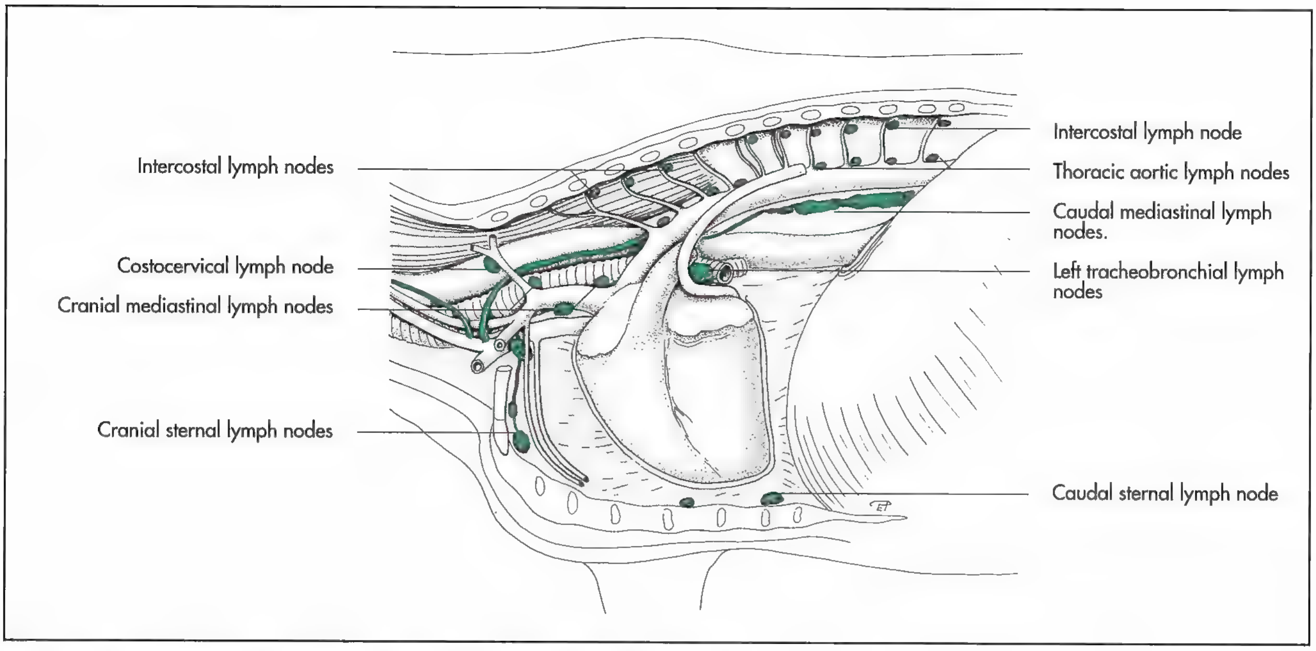

Fig. 13-10. Lymph nodes of the thorax of the ox, schematic (Najbrt, 1982).

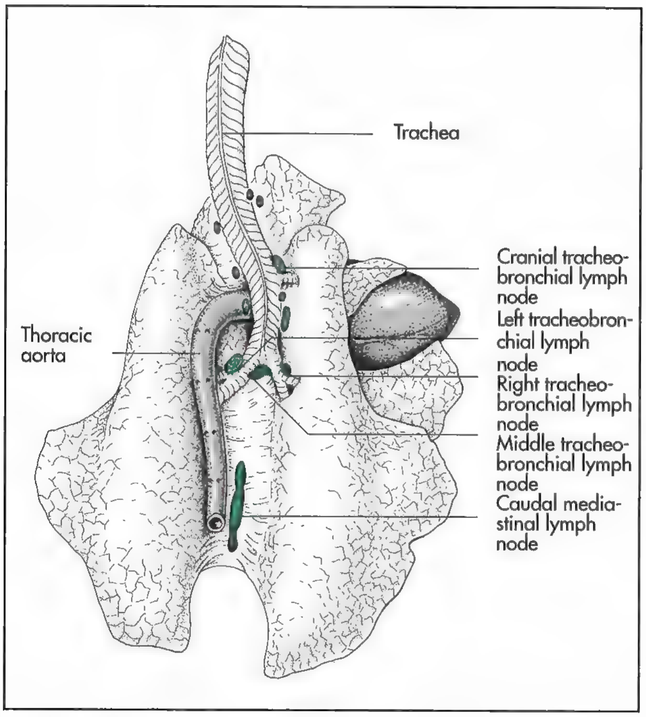

Fig. 13-11. Tracheobronchial lymph nodes of the lung of the ox, schematic, dorsal aspect (Najbrt, 1982).

ing in the dog and cat, although in 25% of cats a phrenic lymph node is present next to the caval foramen. In ruminants the caudal mediastinal lymph nodes form a relatively large mass on the dorsal aspect of the esophagus (Fig. 13-10 to 12).

Enlargement of these lymph nodes can cause obstruction of the esophagus in these species. The tributary territory of the mediastinal lymph centre comprises the organs within the mediastinum, including the heart, the trachea, the esophagus and the thymus. It receives efferent lymph vessels from other thoracic lymph nodes, the diaphragm and abdominal organs located just caudal to the diaphragm.

Bronchial lymph centre

The bronchial lymph centre consists of the **tracheobronchial** (sometimes called bifurcational) **lymph nodes** (lnn. tracheobronchales seu bifurcationes) located about the bifurcation of the trachea (Fig. 13-10 to 12). They are grouped into a right, middle and left set of lymph nodes. In ruminants and pigs, which have a tracheal bronchus, there is an additional cranial tracheobronchial group. Small **pulmonary lymph nodes** (lnn. pulmonales) may be present within the lung tissue along the main bronchi (Fig. 8-26). These lymph nodes are important for lymphatic drainage of the lungs.

In the horse the **left tracheobronchial group** is of special importance with regards to the pathogenesis of the **paralysis** of the **left recurrent laryngeal nerve.** It is hypothesised that inflammation of these lymph nodes could spread to the adjacent nerve or that enlargement of the lymph nodes could mechanically damage the nerve, thus leading to the clinical condition of laryngeal hemiplegia (roaring).

Lymph nodes of the abdomen

The abdominal cavity and its organs are drained by several groups of lymph nodes along the abdominal aorta, located in the lumbar region and at the origin of the intestinal arteries. Additional lymph nodes are found close to the organs they drain and are described together with these organs, in chapter 7.

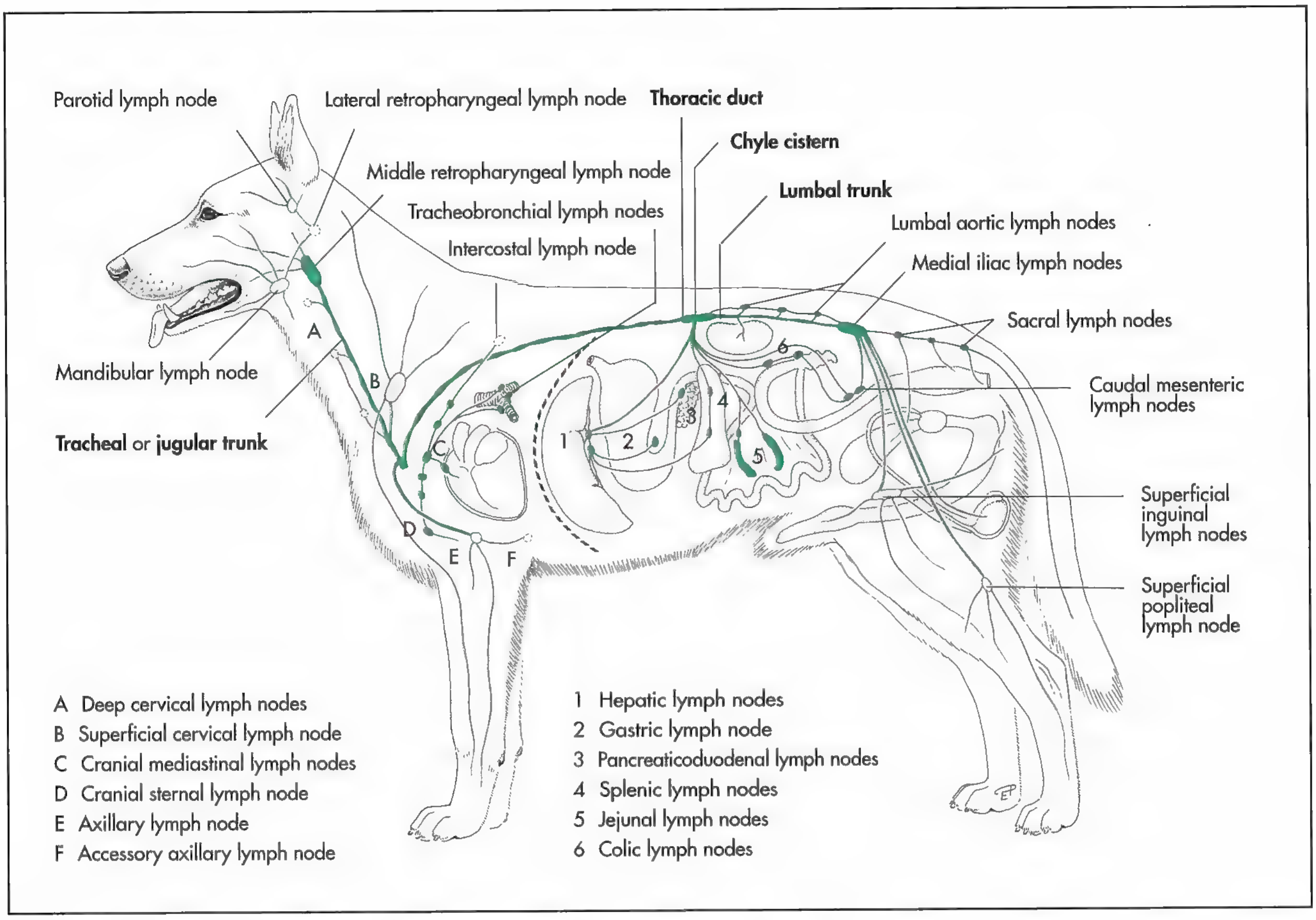

Fig. 13-12. Lymphatic system of the dog, schematic (Budras, Fricke and Richter, 1996).

The **three lymph centres** associated with the drainage of the abdominal viscera have tributary territories broadly corresponding to those of the celiac, cranial mesenteric and caudal mesenteric arteries. The efferent vessels of these centres converge to form the chyle cistern.

Lumbar lymph centre

The lumbar lymph centre consists of the **lumbar aortic and renal lymph nodes.** The lumbar aortic lymph nodes lie either side of the aorta, between the transverse processes of the lumbar vertebrae (Fig. 13-12). Hemal nodes may also be present in the same location in ruminants.

The lumbar lymph nodes receive afferent lymph vessels from the abdominal roof and from efferent vessels of more caudally located lymph nodes. The lymph drainage from the lumbar lymph centre is received by the **chyle cistern** (cisterna chyli).

Renal lymph nodes are associated with the renal vessels and drain the kidneys.

Celiac lymph centre

The celiac lymph centre includes the lymph nodes located within the region supplied by the celiac artery. These are the celiac, splenic, gastric and pancreaticoduodenal lymph nodes (Fig. 13-12 to 14). In ruminants the gastric lymph nodes are subdivided in ruminal, reticular, omasal and abomasal nodes. Their tributary territories are indicated by their names. Their efferent vessel form the celiac lymphatic trunk, one of the radicles of the **chyle cistern.**

Cranial mesenteric lymph centre

The cranial mesenteric lymph centre includes the cranial mesenteric, jejunal, cecal and colic lymph nodes. They show considerable interspecies variations with regards to number, form and location (Fig. 13-12 and 13).

They drain the small intestines and the large intestines as far distally as the transverse colon. Their efferent vessels converge to form the cranial mesenteric trunk, which unites with the caudal mesenteric trunk in the intestinal trunk before it joins the chyle cistern.

Caudal mesenteric lymph centre

The caudal mesenteric lymph centre consists of the caudal mesenteric lymph nodes, which receive the lymph from the descending colon (Fig. 13-12). Its efferent vessels form the caudal mesenteric trunk, which opens into the **chyle cistern.**

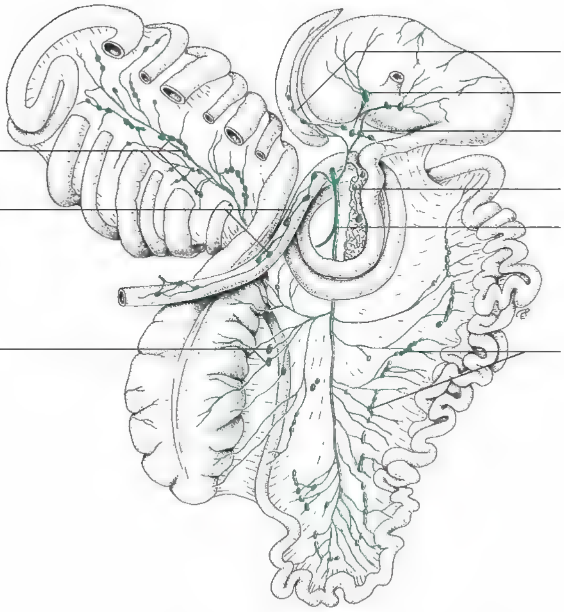

Fig. 13-13. Lymph nodes and lymph vessels of the intestine of the pig, schematic (Najbert, 1982).

Lymph nodes of the pelvic cavity and the pelvic limb

The tributary territories of the lymph nodes of the pelvis often overlap with those associated with the abdominal wall (Fig. 13-14). This is of clinical importance with regards to the removal of tumours of the mammary glands in dogs.

Iliosacral lymph centre

The iliosacral lymph centre comprises the:

- Medial iliac lymph nodes (lnn. iliaci mediales),
- Lateral iliac lymph nodes (lnn. iliaci laterales),
- Hypogastric lymph nodes (lnn. hypogastrici),
- Sacral lymph nodes (lnn. sacrales) and
- Anorectal lymph nodes (lnn. anorectales).

The **medial iliac lymph nodes** are the main group of the iliosacral lymph centre and are located at the quadrification of the aorta (Fig. 13-14). These nodes are the secondary filtration centres through which the efferent lymph from the other lymph nodes of the pelvic viscera and the hind limbs flow. This is of special clinical relevance, when tumours occur in this region, e.g. cancer of the testicles, as cancerous cells are transported directly to the medial iliac lymph nodes without passing through another lymph node. The medial iliac lymph nodes give origin to the lumbar trunks, which open into the chyle cistern.

The **lateral iliac lymph nodes** are lacking in the dog and cat and are inconsistent in the other domestic mammals. When present they are found at the bifurcation of the deep circumflex ilial artery.

Other lymph nodes belonging to the iliosacral centre are found **ventral to the sacrum** (sacral lymph nodes), lateral to the **rectum** (anorectal lymph nodes) and at the **internal iliac artery** (hypogastric lymph nodes). These various lymph nodes drain the adjacent structures.

Deep inguinal (iliofemoral) lymph centre

The deep inguinal lymph centre comprises nodes located along the course of the external iliac artery or its femoral continuation (in the cat and horse) (Fig. 13-14).

Their tributary territory includes the adjacent body wall and the thigh. They also receive efferent lymph vessels from the superficial inguinal nodes in the cat and from the popliteal nodes in the horse. Their efferent vessels drain to the medial iliac nodes.

Superficial inguinal lymph centre (Lymphocentrum inguinale superficiale)

The superficial inguinal lymph centre comprises the following lymph nodes:

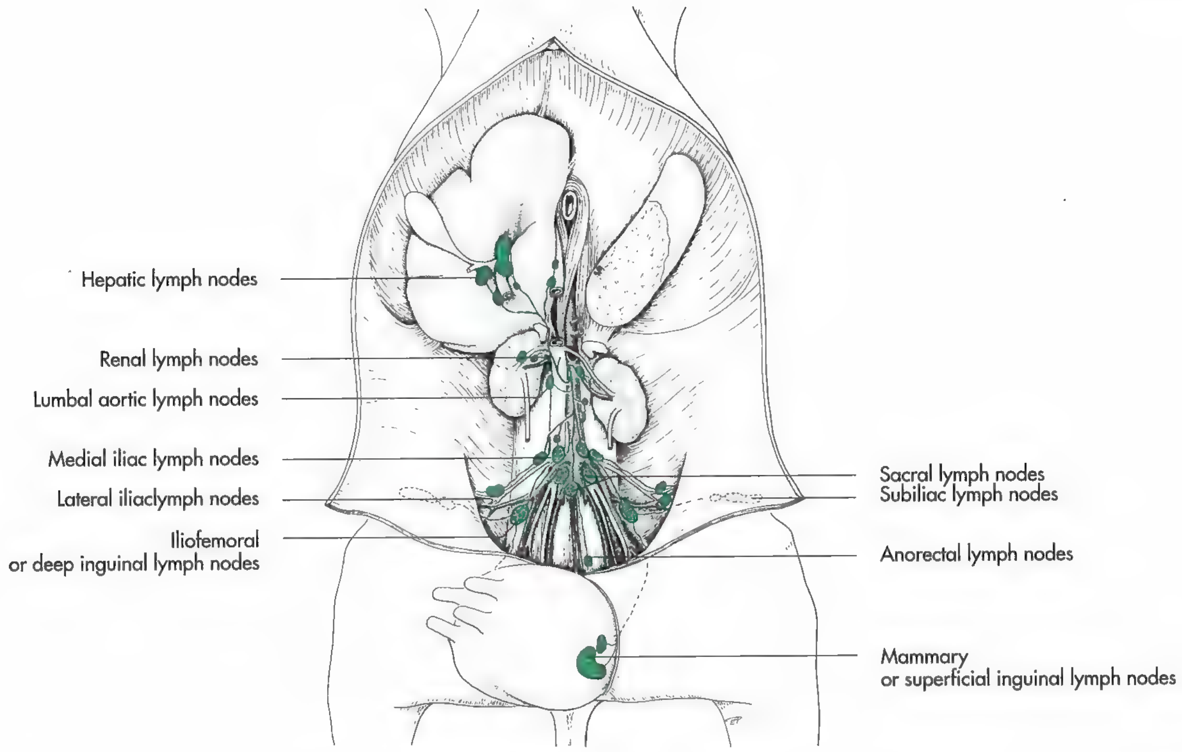

Fig. 13-14. Lymph nodes and lymph collecting ducts of the abdominal cavity of the ox, ventral aspect (Baum, 1912).

- Superficial inguinal lymph nodes (lnn. inguinales superficiales, also called scrotal or mammary lymph nodes,
- Subiliac lymph node (missing in the dog, rare in the cat),
- Coxal lymph node (ln. coxalis),
- Lymph node of the paralumbar fossa (ln. fossae paralumbalis) and
- Epigastric lymph nodes (lnn. epigastrici).

The **superficial inguinal lymph centre** drains the flank, the caudoventral part of the abdominal wall, the scrotum and the mammary glands (Fig. 13-14). Hence the superficial inguinal lymph nodes should be examined and may have to be removed, when mammary tumours are excised. The efferent vessels of these lymph nodes is drains in to the medial iliac lymph nodes.

Ischial lymph centre (lc. ischiadicum)

The ischial lymph centre consists of the ischial lymph node, which is located on the lateral aspect of the sacrosciatic ligament close to the ischial tuberosity. It receives the lymph from the caudal part of the rump and thigh and in the cat from the efferent lymph vessels from the popliteal node. Its efferent vessels drain to the iliosacral lymph node. This lymph node is not present in the dog.

Popliteal lymph centre (lc. popliteum)

The popliteal lymph centre is the most distal centre of the pelvic limb and comprises superficial and deep popliteal lymph nodes, which are located within the popliteal fossa caudal to the stifle. In the dog and cat the superficial popliteal nodes are easily palpable through the skin. The popliteal centre drains the distal part of the limb and directs its efferent flow to the medial iliac centre, except in the horse, in which it passes to the deep inguinal nodes.

Lymph collecting ducts

The major lymph-collecting channel is the **thoracic duct** (ductus thoracicus). Its lymph, also called chyle, appears milky due to the emulsified fat it received from the intestinal tract. The thoracic duct begins between the crura of the diaphragm as a cranial continuation of the **chyle cistern.** It bifurcates or trifurcates dorsal to the aorta and the branches are connected by a network of branches, forming a widespread plexus, through which the intercostal arteries pass.

The thoracic duct passes through the **aortic hiatus** into the mediastinum and continues as a single duct cranially and ventrally over the left side of the aorta. Before it opens into the left jugular vein or the cranial vena cava it may split again into several terminal branches. Normally the lymph vessel joins the venous system at the **jugular venous angle,** the point of confluence of the external and internal jugular veins or the junction of the jugular and subclavian veins (see chapter 12).

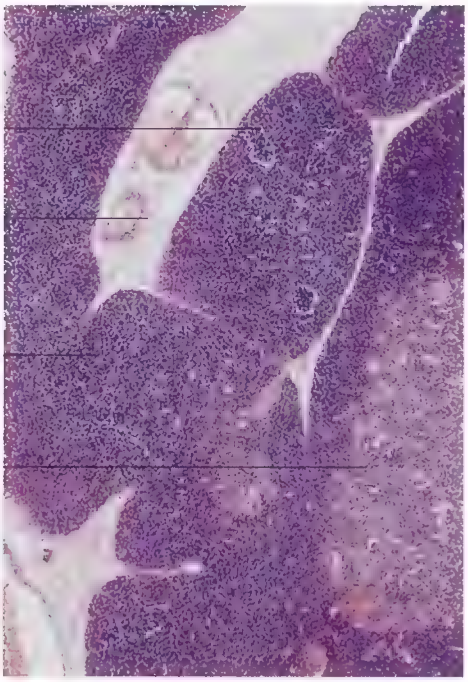

Fig. 13-15. Histological section of the thymus of a cat.

Fig. 13-16. Thymus of a calf, dorsal aspect (courtesy of PD Dr. S. Reese, Munich).

The thoracic duct receives the lymph from the left side of the head and neck via the **left jugular** (tracheal) lymph duct and from the left forelimb by the lymph collecting duct, which is formed by the convergence of the efferent vessels of the axillary and superficial cervical lymph nodes. Lymph from the right side of the **head and neck** (right jugular or tracheal lymph duct) and the right thoracic limb is returned via the right lymphatic duct to the venous system at the venous angle.

The **chyle cistern** has the shape of a spindle or sac and lies retroperitoneally dorsal to the aorta extending from the diaphragmatic crura to the origin of the renal arteries (Fig. 13-12). The flow of the lymph is assisted by the respiratory movements of the diaphragm and the pulsation of the aorta. It receives afferent vessels at its caudal aspect from the lumbar lymph trunks, which are continuous with the lymph trunks of the pelvic area.

The **chyle cistern** also receives afferent vessels from the visceral trunk, from the abdominal organs, which is formed by the convergence of the celiac, cranial and caudal mesenteric trunks. In some species these open into the chyle cistern individually. The cranial and caudal mesenteric trunk may unite to form an intestinal lymph trunk before converging with the celiac trunk.

Thymus

The thymus is the control organ of the immune and lymphatic systems (Fig. 13-15 to 17). Its importance is greatest in the juvenile animal and accordingly it reaches its maximum development three weeks after birth in dogs, nine months postpartum in pigs and one year after birth in the horse. After this time it begins to gradually **involute** until the animal reaches sexual maturity. Regression starts at the cranial, cervical part of the organ, so that the thoracic part remains longer. As it decreases in size and looses its lymphoid structure, it is replaced by fat. However, evidence of the thymus can be seen in most animals regardless of age.

The thymus has a **paired origin** from the third pharyngeal pouches and the buds grow down the neck beside the trachea and invade the **mediastinum,** in which they extend to the pericardium. In the pig and in ruminants the thymus is divid-

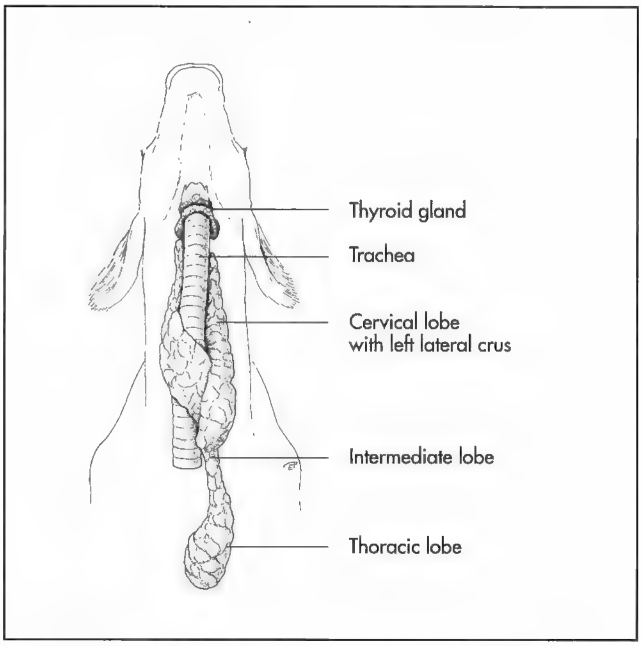

Fig. 13-17. Topography of the thymus of the calf, schematic.

Fig. 13-18. Spleen of a pig, cross section (courtesy of PD Dr. J. Maierl, Munich).

Fig. 13-19. Spleen of a pig, visceral surface (courtesy of PD Dr. J. Maierl, Munich).

ed into an **unpaired thoracic part** (lobus thoracicus thymi) and **left and right cervical parts** (lobus cervicalis thymi dexter et sinister) (Fig. 13-16 and 17). The two parts are joined together by the **intermediate lobe** (lobus intermedius) at the thoracic inlet. In the dog and horse the cervical part regresses prematurely and the thymus is represented by the thoracic part only.

In the dog the thoracic part is divided into a **larger right lobe** and a **smaller left lobe** and is located almost entirely in the cranial mediastinum along the sternum extending to the pericardium at its caudal end.

In the pig the thymus is particularly well developed and consists of a **paired cervical** and a **paired thoracic** part. In the piglet its bulbous cranial end may extend to the base of the skull. The cervical portion is located ventral and to the side of the trachea.

In the calf the thymus is particularly **large** and extends from the **larynx to the pericardium.** It is distinctively divided into a **paired cervical** and an **unpaired thoracic** part, which are connected by a narrow isthmus ventral to the trachea (Fig. 13-16 and 17). The cervical part consists of a body that divides into two tapering horns along the trachea. The thoracic part is located in the left half of the dorsal part of the cranial mediastinum.

In most horses the thymus is represented by a **bipartite** thoracic part only. However a cervical part may extend beside the trachea in the caudal part of the neck. It is often separated from the thoracic part and may consist of several masses. The thoracic part extends dorsal to the sternum from the cranial mediastinum to the 4th to 5th rib. Its larger left lobe extends to the left lung lobe and the brachiocephalic trunk dorsally. In a one-year-old foal the thymus can reach 15 cm in length and 12 cm in height.

Macroscopically the thymus is a light-grey, distinctly lobulated organ with a pink tinge in fresh material. Its **polygonal lobules** (lobuli thymi) are separated from each other by a delicate, but distinct connective tissue capsule. Microscopically each lobule is divided into an **outer cortex** and an **inner medulla** (Fig. 13-15). Lymphopoetic cells migrate from the **bone marrow into the cortex,** where they divide and mature to form **T-lymphocytes.** Within the cortex the T-lymphocytes become equipped with **receptors,** that recognise the proteins belonging to the body. If the T-lymphocytes fail to recognise proteins of the body the **immune system** starts to react against these components. This results in the autoimmune diseases, such as multiple sclerosis or rheumatoid arthritis.

Although the medulla also contains lymphocytes, their number is less. Cells of the interstitial tissue form agglomerations known as **Hassall bodies,** the function of which is not fully understood. Their number is highest at the time of birth and in very young animals (about 1 million). (Further details can be found in histology textbooks.)

As well as its lymphopoetic function, the thymus is hypothesised to have an endocrine function. The "thymus factor" stimulates growth and differentiation of peripheral lymphatic organs. Removal of the thymus in newborn mice result in severe growth retardation, impaired development of lymphatic organs and death two weeks post partum.

Spleen (lien, splen)

The spleen is a reddish-brown to gray organ, depending on the species, situated caudal to the diaphragm within the left cranial part of the abdomen. It is located entirely within the peritoneum in all domestic mammals other then ruminants, where half

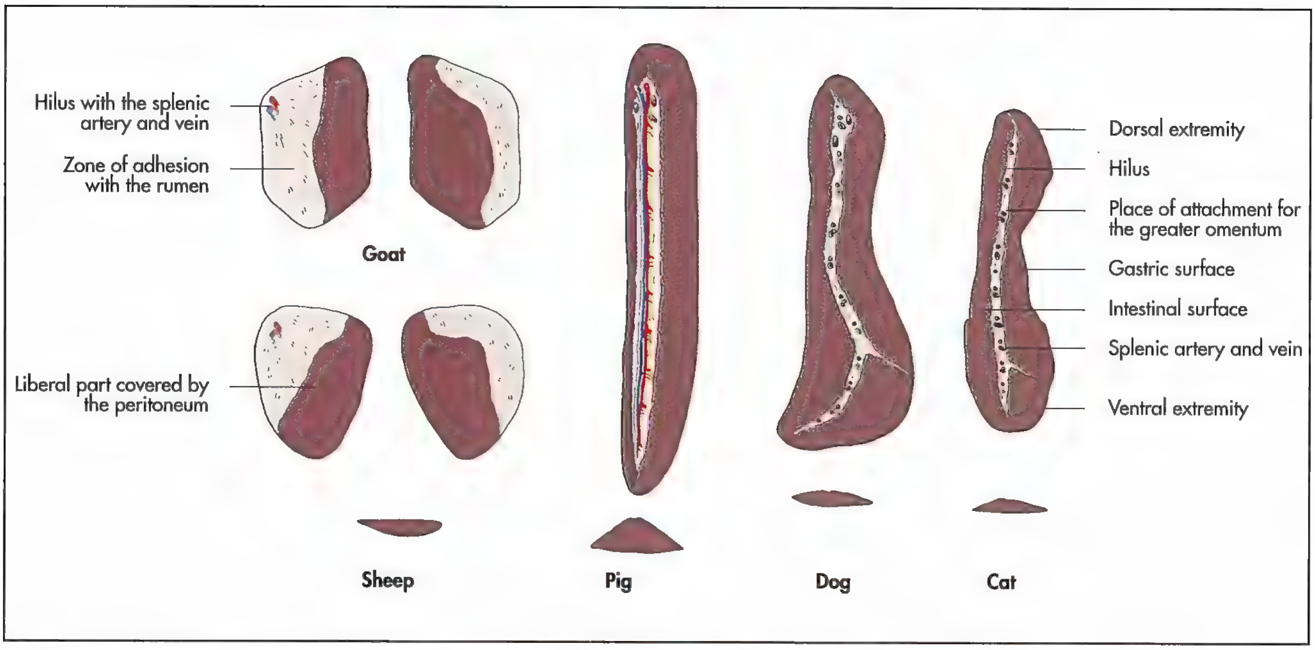

Fig. 13-20. Spleen of the small ruminants, pig, dog and cat, medial aspect and cross section, schematic.

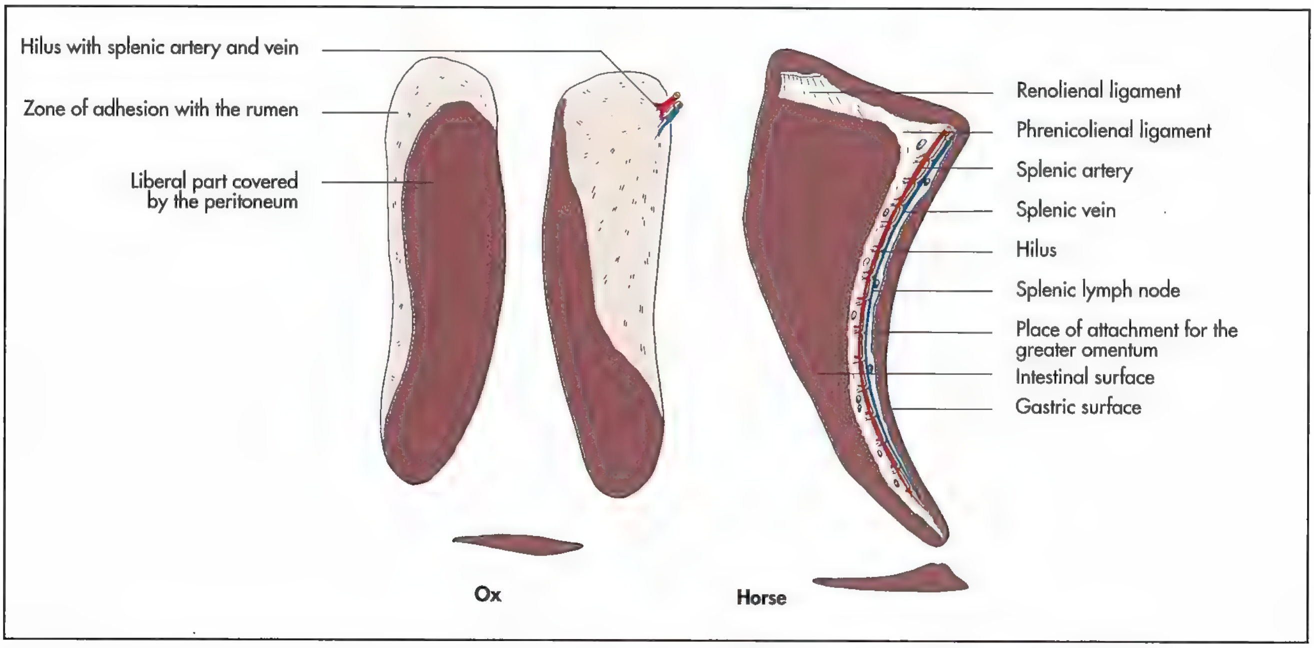

Fig. 13-21. Spleen of the ox (medial and lateral aspect, cross section) and horse (medial aspect, cross section), schematic.

of the spleen extends into the retroperitoneal attachment zone between the diaphragm and the dorsal sac of the rumen.

The spleen is attached to the stomach by the **gastrosplenic ligament,** which is part of the omentum. In the horse an additional ligament is present between the spleen and the left kidney, the **nephrosplenic** or **renosplenic ligament** (ligamentum lienorenale), creating the nephrosplenic space, in which parts of the intestines can become trapped resulting in colic.

The basic form of the spleen varies in the different domestic mammals (Fig. 13-18 to 23): it is **falciform** in the horse, **tongue-shaped** in pigs, **boot-shaped** in carnivores, **leaf-**

Fig. 13-22. Spleen of an ox, proximal end, cross section (courtesy of PD Dr. S. Reese, Munich).

Fig. 13-23. Spleen of an ox, distal end, cross section (courtesy of PD Dr. S. Reese, Munich).

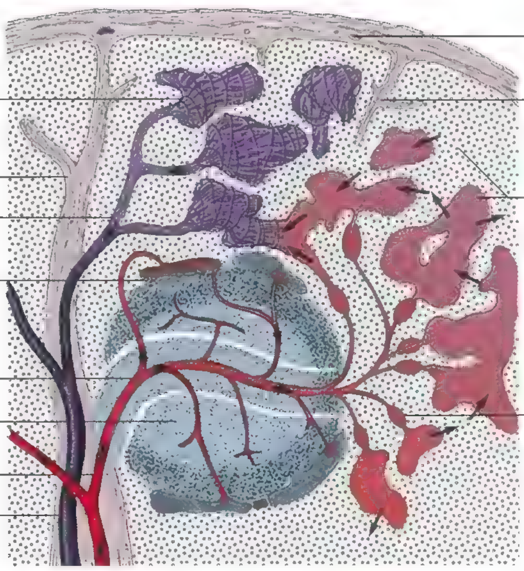

Fig. 13-24. Microvascularisation of the spleen (Liebich, 2004).

shaped in small ruminants and resembling a wide strap in the ox (Fig. 13-22 and 23).

It has two surfaces, the diaphragmatic surface and the visceral surface, which is marked by the hilus in all domestic mammals other than the ruminants.

Several accessory spleens may be present, close to the hilus or embedded in the greater omentum, which originate from dispersed primordial cells during embryonic development.

The spleen is enclosed by a **soft tissue capsule,** which is rich in smooth muscle fibres and extends trabeculae into the

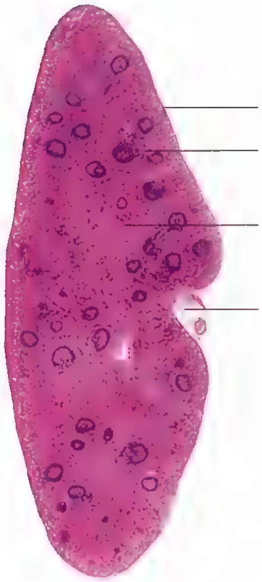

Fig. 13-25. Histological section of the spleen of a cat (Liebich, 2004).

organ. The **parenchyma** of the spleen consists of the **red** and **white splenic pulp** (Fig. 13-24 and 25). The **red pulp** is composed of the venous sinuses, which are lined by an endothelium. The white pulp, which accounts for about 1/5 of the splenic volume, consists of diffuse and follicular lymphoid tissue. (A more detailed description can be found in standard histology textbooks.)

Blood supply, lymphatic drainage and innervation of the spleen

The blood vessels of the spleen are the splenic artery (a. lienalis) and the celiac artery. The splenic vein drains into the portal vein. The blood vessels pass through the **hilus** and course in the **trabeculae,** branching repeatedly as they become smaller in diameter. They finally leave the trabeculae and become surrounded by lymphoid tissue, forming **central arteries** within the white pulp. The central arteries enter the red pulp, where they branch into about 50 small straight arterioles that open into **capillary** beds.

The venous side of the vascular pathway through the spleen begins in the **venous sinuses,** which communicate with each other. The wall of these sinuses is composed of endothelial and reticular cells with an incomplete basal membrane. These sinuses coalesce into veins of the red pulp, which finally merge to become the **trabecular veins.** (A more detailed description can be found in standard histology textbooks.)

The spleen receives **parasympathetic** and **sympathetic nerve fibres** from the solar plexus.

Lymphatic drainage of the spleen is to the splenic lymph nodes located at the hilus of the organ. Their efferent vessel joins the celiac trunk to drain into the chyle cistern.

Function

Several diverse functions have been attributed to the spleen: it stores and concentrates erythrocytes and releases them, when needed. It filters the blood and removes worn-out erythrocytes from the circulation. From the haemoglobin it extracts iron and releases it again for reuse. It produces lymphocytes and monocytes and has an important function in the production of antibodies. However, the spleen is not essential to life, as most of its functions are taken over by other tissues in its absence. Dogs and cats can lead a healthy life after splenectomy, however animal athletes do not go back to their former performance levels.

Clinical terms related to the immune system and lymphatic organs:
Lymphangitis, lymphadenitis, lymphangiography, thymectomy, thymopathy, splenitis, splenectomy, splenomegaly.

14 Nervous system (systema nervosum)

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The nervous system is responsible for the stimulus-response interaction between the environment and the organism, regulation and co-ordination of other body systems, together with the control of the endocrine, immune and the sensory organs. An environmental change provides a stimulus, that is recognised by the appropriate receptor organ. The provoked stimulus causes a reaction by an effector organ. In simple organisms, the receptor cell itself is connected directly to the effector cell. In higher organisms, the receptor and effector organs lie separate and are connected by neurons, which transmit the information from cell to cell.

Structure

To facilitate understanding of the nervous system basic terms are explained. For a more detailed description see histology, neurophysiology and neuroanatomy textbooks.

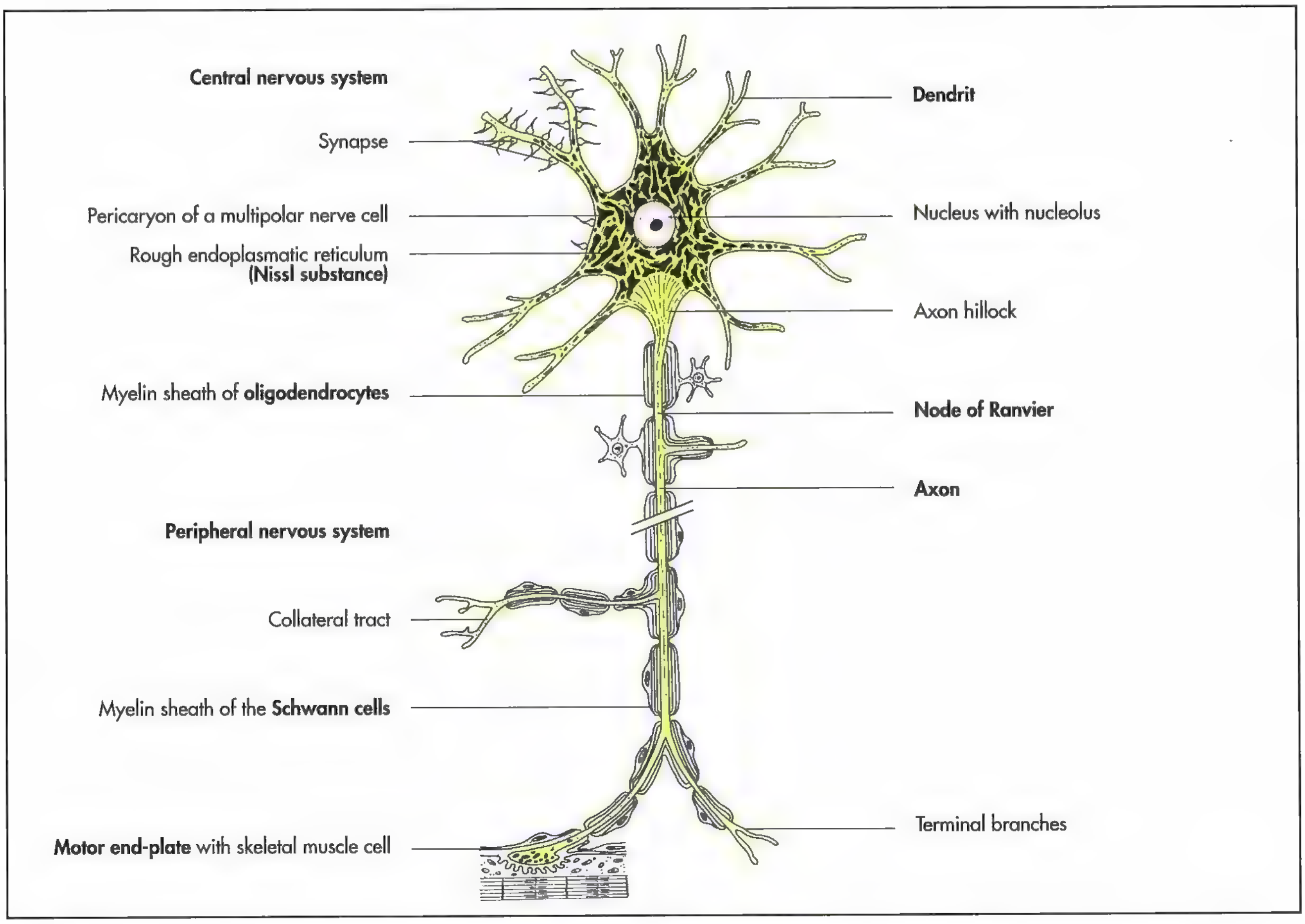


Fig. 14-1. Motor neuron showing the central cell body and peripheral nerve fibre, with muscle cell, schematic (Liebich, 2004).

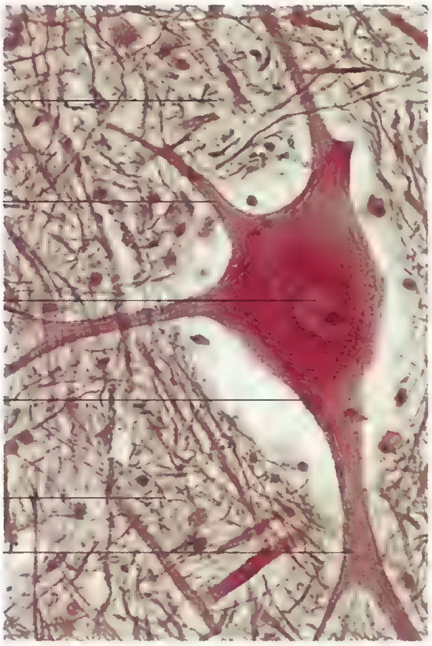


Fig. 14-2. Multipolar neuron of the spinal cord with neurotubuli and neurofilaments, histological section.

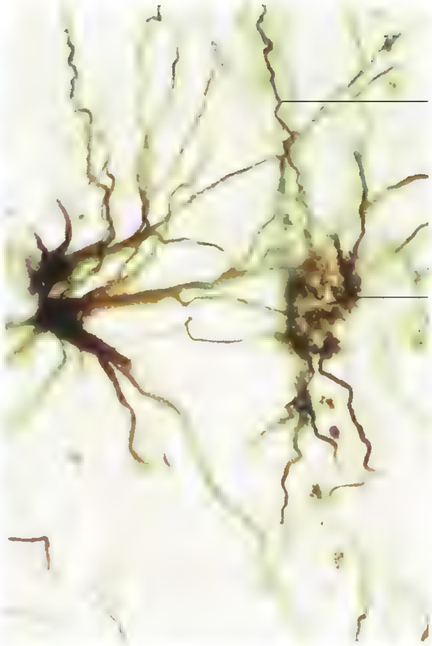


Fig. 14-3. Macroglia of the spinal cord (astrocytes), histological section (Liebich, 2004).

Neurons or **nerve cells** are the basic, functional units by which the nervous system is constructed. A typical neuron is an elongated cell, with a cell body and various processes. These processes can be distinguished by the direction in which they transmit impulses: **dendrites** are usually multiple and transmit impulses toward the cell body. The **axon** is always single at its origin and conveys impulses away from the cell body (Fig. 14-1 and 2).

The arrangement of the processes, which vary considerably in number, length and form, permit the classification of the neurons into **unipolar, bipolar** and **multipolar neurons** (Fig. 14-2).

To maintain normal function, neurons need the support of **glial cells.** These supporting cells assist in the nutrition of the neurons, hold the neurons in place and provide nerve fibres with cytoplasm investments that insulate them from their surroundings, preventing the nerve impulse from spreading to other fibres. The supporting tissue of the brain and the spinal cord are known as **neuroglia** and comprises several cell types: astrocytes, micro- and macroglia, oligodendrocytes and ependymal cells.

Glial cells form the **blood-brain barrier** and play an important role in the **non-specific defence mechanism** of the brain. The ventricles of the brain and the central canal of the spinal cord are lined by **ependymal cells,** which also belong to the glial cell group. **Oligodendrocytes** form sheaths around the conducting elements. The insulating material of the glial cells, **myelin,** is responsible for the colour of the **white matter of the central nervous system.** Nerve fibres within peripheral nerves are supported by the **Schwann cells** and are further protected by connective tissue sheaths. Neurons and glial cells form the **nervous tissue** (textus nervosus).

A **nerve fibre** consists of an **axon** and its surrounding sheath formed by **neuroglia.** Based on the nature of the information these fibres convey, they can be grouped into **motor, sensory** and **autonomic nerve fibres.** An alternative classification is based on the direction in which impulses travel. It distinguishes **afferent fibres,** which conduct impulses from the periphery to the central nervous system from **efferent fibres,** which convey impulses from the central nervous system to the periphery.

The term nerve is applied to a complex structure consisting of many peripheral nerve fibres bound together by supporting cells and connective tissue sheaths.

A **ganglion** is a collection of nerve cell bodies surrounded by connective tissue and a dense vascular network associated with a nerve, outside the central nervous system.

Aggregations of nerve cell bodies within the central nervous system are known as **nuclei,** and generally have similar function. Nerve trunks consists of a multitude of nerve fibres within the brain or spinal cord, that extend from nuclei. They constitute the **white matter** of the central nervous system, whereas the bodies of the nerve cells and glial cells constitute the **grey matter.**

The term **plexus** is applied to a fine network of nerves, connected with each other.

Synapses are interneural and neuromuscular connections, where impulses are transmitted from one cell to another. A nerve impulse prompts the release of a specific chemical transmitter substance at the presynaptic membrane, which either initiates a fresh impulse, thus having an excitatory effect on the postsynaptic cell membrane or produces an inhibitory effect.

Subdivisions

Although the nervous system actually forms a single, integrated system, it is convenient for descriptive purposes to divide it into parts. The division can be made on topographical grounds, distinguishing the **central nervous system** (systema nervosum centrale), consisting of the **brain** (encephalon) and **spinal cord** (medulla spinalis) from the **peripheral nervous system** (systema nervosum periphericum) composed of cranial and spinal nerves.

An alternative division distinguishes the somatic system that is concerned with locomotion from the visceral or autonomic system, concerned with functions related to the inner organs, such as heart and respiratory rate. The latter includes the **sympathetic** and the **parasympathetic nervous systems.**

Functions

The functions of the nervous system can be divided into:

- **Sensory functions,**
  - exteroceptive,
  - proprioceptive,
  - vegetative,
- **Motor functions,**
  - somatic and
  - visceral.

The **sensory part** of the nervous system responds to various stimuli delivered to the organism. The pathways that arise with skin or mucosa receptors are concerned with the **exteroceptive** sensations, such as touch, temperature and pain. **Proprioceptive** pathways are concerned with the stance and position of the body or body parts. The receptor organs measure the tension within the tendons and muscles, in which they are located. In this case the receptor and effector organs are identical.

Vegetative or **visceral** pathways originate in the receptors of the blood vessels and viscera.

The **motor part** of the nervous system is responsible for co-ordinating the movement of muscle cells. The **somatic** pathways control the striated musculature of the head, trunk and limbs. The **visceral** pathways are concerned with the co-ordination of the smooth muscles.

Central nervous system (systema nervosum centrale)

The central nervous system consists of the brain and the spinal cord. The brain is housed within the cranial cavity and surounded by an osseous capsule. The spinal cord runs within the vertebral column. Both are surrounded by several meningeal layers, which enclose a fluid filled space. Thus, the central nervous system is protected by its surrounding bones and the shock-absorbing properties of the cerebrospinal fluid. Without any distinct anatomical division, the brain continues as the spinal cord between the occipital bone and the atlas, the exact limit is drawn between the last pair of cranial nerves and the first pair of cervical nerves.

Spinal cord (medulla spinalis)

Shape and position

The spinal cord is a whitish, **elongated cylinder** with a slight dorsoventral flattening. It has certain regional variations in form and diameter: At two locations, where nerves to the limbs arise, the relative diameter of the spinal cord is increased. The cervical **enlargement** or **intumescence** (intumescentia cervicalis) involves the caudal part of the cervical spine and the initial part of the thoracic spine and gives rise to the spinal nerves that form the brachial plexus that innervates the thoracic limb. The lumbar enlargement (intumescentia lumbalis) gives rise to the spinal nerves, which innervate the pelvic cavity and the pelvic limb. Caudal to the **lumbar enlargement** the spinal cord tapers into an **elongated cone** (conus medullaris), which is finally reduced to form the **terminal filament** (filum terminale) (Fig. 14-5 and 6).

Corresponding to the divisions of the vertebral column the spinal cord can be divided into the:

- Cervical spinal cord (pars cervicalis),
- Thoracic spinal cord (pars thoracica),
- Lumbar spinal cord (pars lumbalis),
- Sacral spinal cord (pars sacralis) and
- Coccygeal, or caudal, spinal cord (pars coccygea).

The **spinal cord** is divided into two symmetric halves by the **dorsal groove** (sulcus medianus dorsalis) and the **ventral median fissure** (fissura mediana ventralis)

On the dorsolateral aspect of each side, nerve fibres enter the spinal cord, forming the **dorsal spinal root** (radix dorsalis), while on the ventrolateral aspect, nerve fibres leave the spinal cord, forming the **ventral root** (radix ventralis) (Fig. 14-7).

The nerve fibres of each root are bound together at the **intervertebral foramen,** where dorsal and ventral roots joint to form the **spinal nerve** (n. spinalis). Although the spinal cord itself is not segmented, it can be divided into **segments** based on the spinal nerves. Each pair of spinal nerves is responsible for the innervation of a body segment.

The **spinal ganglia** are located within the **dorsal roots,** and contain sensory neurons, with the exception of the first cervical nerve, which has no or only a rudimentary ganglion. In the foetus, the spinal cord and vertebral column have the same length and each spinal nerve leaves the vertebral canal through the intervertebral foramen at the level of its origin.

During development, however, the vertebral column increases more in length than the spinal cord and the caudal end of the spinal cord is cranial to the caudal end of the vertebral column. Instead of leaving the vertebral canal at the site of their origin, the spinal nerves have to pass caudally within the vertebral canal until they can leave through their appropriate intervertebral foramen. **Sacral** and **caudal spinal roots** stream caudally beyond the conus medullaris to exit at their respective intervertebral foramina. Collectively these roots are designated **cauda equina,** due to their shape, which resembles the tail of a horse (Fig. 14-6).

A transverse section of the spinal cord shows a **central mass** of **grey matter** (substantia grisea) perforated in the

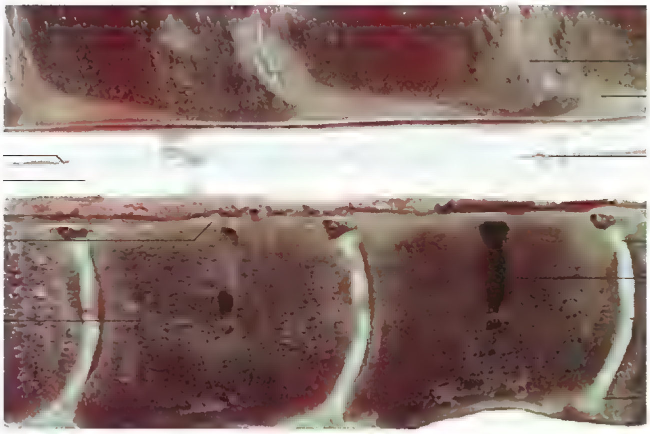


Fig. 14-4. Vertebral column with spinal cord of a horse, median section.

Fig. 14-5. Cauda equina of a dog, dorsal aspect (courtesy of Dr. R. Macher, Vienna).

middle by the **central canal** (canalis centralis). The central canal is the caudal continuation of the ventricles of the brain and passes through the whole of the spinal cord. It is lined by **ependymal cells,** a subgroup of glial cells and filled with **cerebrospinal fluid** (liquor cerebrospinalis).

The grey matter is surrounded by the **white matter** (substantia alba). The spinal cord and the spinal roots are surrounded by protective, soft tissue layers termed **meninges.** All parts of the spinal cord are well vascularised by a dense capillary network. Vascular supply is also provided within the vertebral canal by large veins, embedded in soft tissue, rich in fat, which are not enclosed by the meninges.

The soft tissue layers and the cerebrospinal fluid provide the spinal cord with protection against the mechanical forces it is submitted to.

Structure

The spinal cord is a **bilaterally symmetrical** structure, which is divided by different grooves of varying depths (Fig. 14-7). Dorsally there is the **dorsal median sulcus** (sulcus medianus dorsalis) at the surface and a **dorsal median septum** (septum medianum dorsale), that extends from the sulcus into the spinal cord. On the ventral surface, the spinal cord is marked by the deep **ventral median fissure** (fissura mediana ventralis).

A dorsolateral sulcus is visible on each side, where **dorsal nerve roots** (radices dorsales) enter the spinal cord. A corresponding ventrolateral sulcus, where **ventral nerve roots** (radices ventrales) leave the spinal cord is reduced to a shallow groove.

Grey matter (substantia grisea)

In transverse section, the grey matter appears butterfly or **H-shaped** (Fig. 14-7 to 9). This characteristic shape is due to the two dimensional appearance of the dorsal, ventral and lateral columns of the grey matter on transverse section, where they appear as **dorsal** (cornu dorsale) and **ventral horns** (cornu ventrale). The dorsal and the more pronounced ventral horns are connected by the lateral intermediate substance, which extends to form an additional lateral horn in the thoracolumbar region. The bilateral symmetrical columns of the grey matter are the:

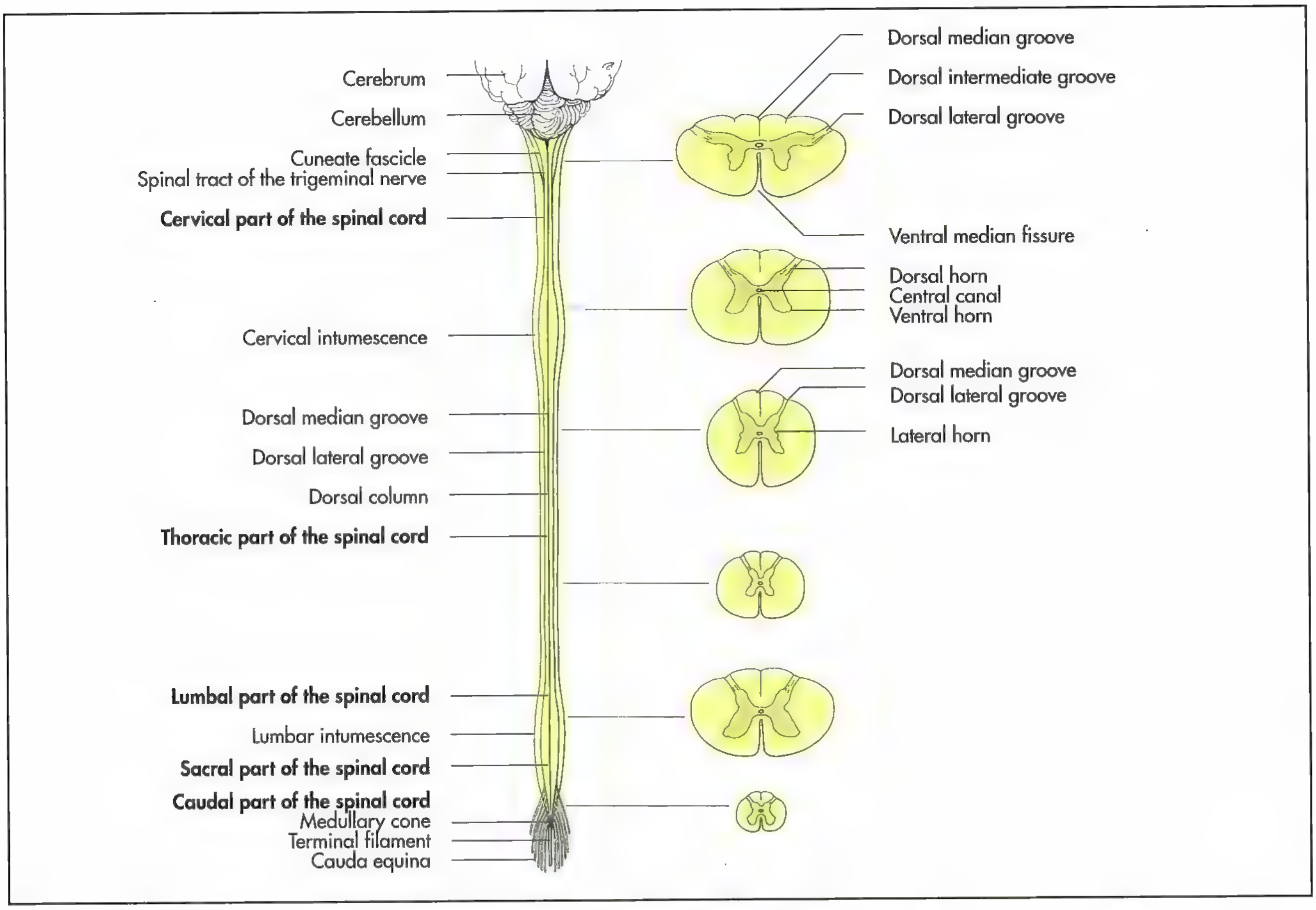


Fig. 14-6. Spinal cord, dorsal aspect and transverse sections, schematic (Najbrt, 1982).

- **Dorsal column** (columna dorsalis) appearing as the dorsal horn (cornu dorsale) in transverse sections,
- **Lateral column** (columna lateralis) appearing as the lateral horn (cornu laterale) in transverse sections and
- **Ventral column** (columna ventralis) appearing as the ventral horn (cornu ventrale) in transverse sections.

The **grey matter** is composed of cell bodies and processes of neurons and glial cells. The dorsal column consists mainly of somatic and afferent visceral neurons, which tend to have their cell bodies grouped together. Clusters of cell bodies with similar functions are termed nuclei, e.g. the nucleus proprius of the dorsal horn. These nuclei may extend the entire length of the spinal cord or may be restricted to certain segments.

The **lateral columns** of the thoracolumbar spine contain the visceromotor neurons. The intermediolateral (sympathetic) nucleus is located within the lateral intermediate substance and contains **sympathetic neurons.** The sacral **parasympathetic** (intermediomedial) nucleus is found in the lateral column of the sacral spinal cord segments and is closely related to the ventral column. The **ventral column** is mainly composed of **motor neurons.** Motor neurons of related skeletal muscles are grouped into motor nuclei.

Spinal cord neurons can be categorised as interneurons or efferent neurons. Spinal interneurons are interposed between a particular input and the resulting output of the spinal cord. Interneurons may be activated either by synaptic input that can arrive from afferent neurons, from descending pathways coming from the brain, from other interneurons or from axonal branches of efferent neurons. Spinal efferent neurons send axons into the white matter to generally form ascending pathways to the brain. They are activated by afferent neurons, which become excited in response to stimulation of viscera, muscles, joints or skin. Spinal efferent neurons send axons through ventral roots to innervate muscles and glands. They may be classified as somatic or autonomic (visceral).

White matter (substantia alba)

The white matter is positioned superficially in the spinal cord, surrounding the grey matter. It is composed mainly of **myelinated ascending** and **descending nerve fibres** (Fig. 14-7). The myelin sheaths are formed by **oligodendrocytes** and are responsible for the white colour of the unstained white matter.

The white matter of each half of the spinal cord is divided into columns or funiculi, which are composed of bundles (fasciculi or tracts) of nerve fibres of common origin, destination and function. There are the:

- Dorsal column (funiculus dorsalis),
- Ventrolateral column (funiculus ventrolateralis).

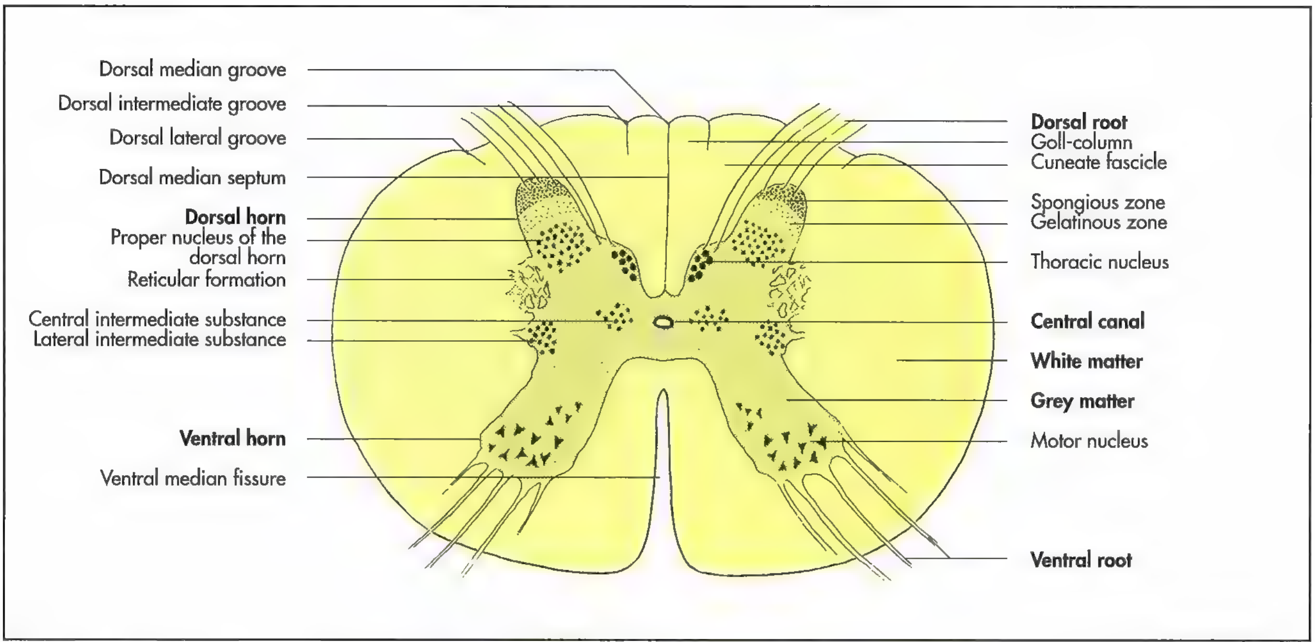


Fig. 14-7. Cervical spinal cord, transverse section, schematic.

The **dorsal column** includes all of the white matter located between the dorsal median sulcus and the line of origin of the dorsal roots of the spinal nerves. The **ventrolateral column** is contained between the dorsal and ventral spinal roots and continues to the ventral median fissure. The ventral fissure penetrates into the white matter, leaving a considerable **commissure** (commissura alba), that consists of myelinated axons crossing from one half of the spinal cord to the other, ventral to the grey matter. The **dorsal column** almost exclusively consists of **ascending spinal tracts** that convey information about superficial and deep sensation to the brain. The **ventrolateral column** consists of ascending sensory as well as descending **motor nerve tracts.**

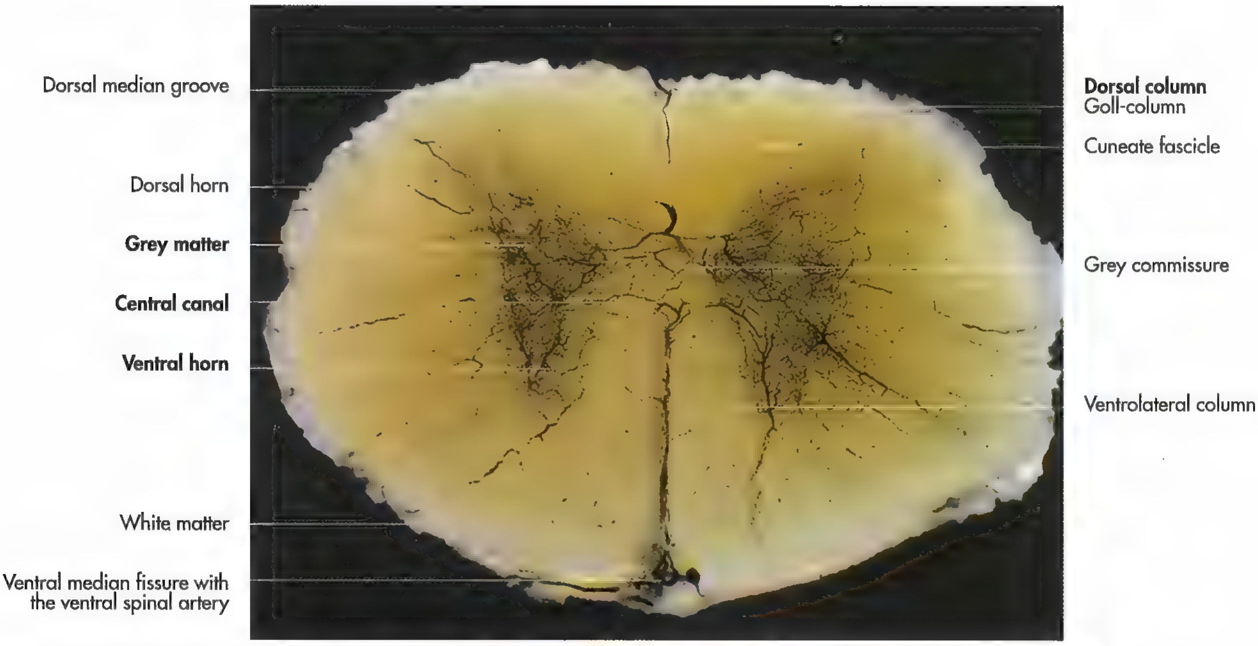


Fig. 14-8. Spinal cord of a sheep after injection of the blood vessels, transverse section.

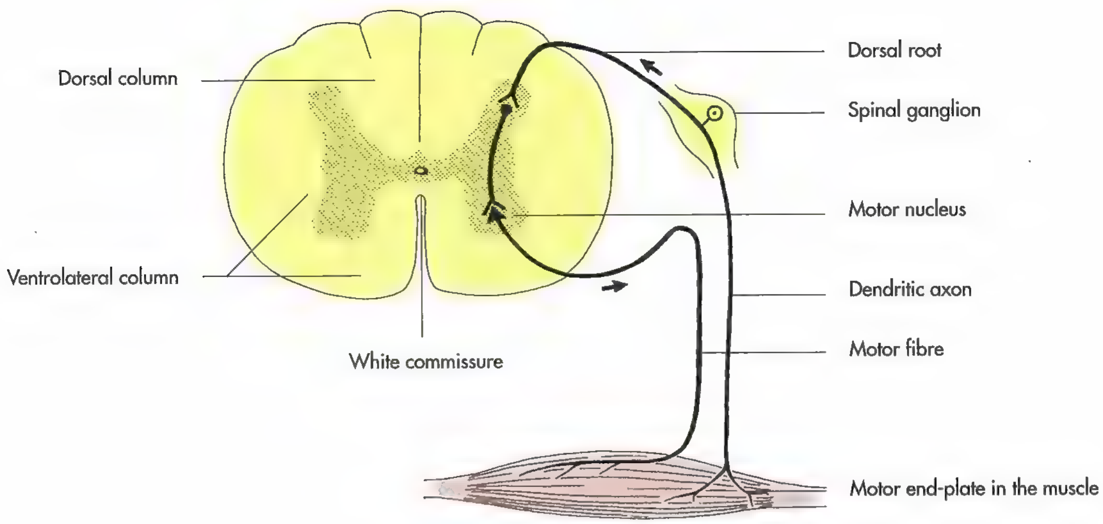


Fig. 14-9. Illustration of a monosynaptic, spinal reflex arc, schematic.

Intersegmental fibres that arise and terminate within the spinal cord are known collectively as the proper fascicle of the spinal cord (fasciculus proprius) and are found bordering the grey matter in all funiculi.

Ascending and descending tracts cannot be distinguished anatomically or histologically, but are determined experimentally by the stimuli-response reaction. For clinical purposes it is important to know that damage to the dorsal column will result in sensory deficits, while damage to the ventrolateral column may result in sensory and motor deficits as well as in paralysis of certain muscles, as for example seen in animals with disc prolapse. Due to the segmental nature of the spinal cord, the extent of the clinical symptoms can provide information regarding the location of the spinal cord lesion.

Reflex arcs of the spinal cord

A reflex is a subconscious, relatively consistent response to a particular stimulus. A typical reflex arc consists of a receptor organ, that responds to a **particular stimulus** (touch, sound, etc.), an afferent neuron that conveys the initiated impulse to the central nervous system, a synapse, that in the simplest version connects the afferent neuron with an efferent neuron, and conveys the impulse from the centre to the effector organ (muscle, gland, etc.) in the periphery.

There are **three typical categories** of spinal reflexes, which are of clinical importance:

- Myotactic reflex,
- Withdrawal reflex and
- Cutaneous trunci reflex.

The **myotactic reflex,** also called **muscle stretch reflex** can be demonstrated by tapping the tendon of a muscle, thus abruptly stretching the muscle and observing its immediate contraction. This type of reflex has a monosynaptic component with primary afferent neurons synapsing directly on efferent neurons, thus this reflex is the fastest and relatively resistant to fatigue.

The **withdrawal reflex** is clinically tested by applying a noxious stimulus to a part of the limb and observing withdrawal of the entire limb. It is a multisynaptic reflex, which is initiated by free nerve endings in the periphery. These enter the dorsolateral fascicle, where they extend over several segments and synapse with interneurons and efferent neurons to finally stimulate the afferent neurons of several muscle groups.

The **cutaneous trunci** reflex is elicited by pricking the skin and observing it twitch, owing to the contraction of the cutaneous trunci muscle. It is an intersegmental reflex, since a number of segments intervene between the afferent input and the efferent output.

Brain (encephalon)

The brain as a whole

The brain is the control organ of the body, and is responsible for the regulation, co-ordination and integration of the rest of the nervous system. Its abilities are resembled by its morphological features. Based on its ontogenetic and phylogenetic development from the rostral part of the neural tube, the brain can be subdivided into five major parts:

- **Rhombencephalon, hindbrain,**
  - Myelencephalon, medulla oblongata, bulb,
  - Metencephalon, pons and cerebellum,

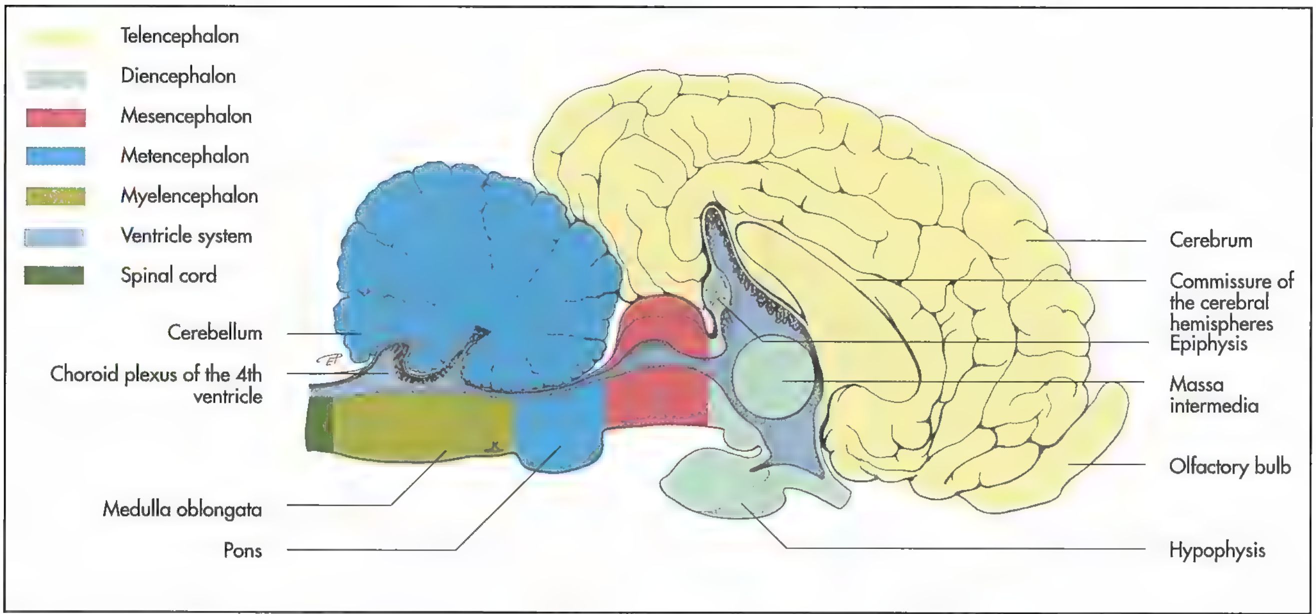


Fig. 14-10. Brain of the horse, median section.

- **Mesencephalon, midbrain,**
- **Prosencephalon, forebrain,**
  - Diencephalon and
  - Telencephalon.

These divisions will be used in the following description of the brain. However, sometimes a simpler division is used based on gross anatomy. Grossly the brain may be divided into:

- Cerebrum,
- Cerebellum,
- Brainstem (truncus encephali),
  - Medulla oblongata, bulb,
  - Pons and
  - Midbrain.

The brain is enclosed in the **cranial cavity,** which is divided into a **larger rostral cavity** for the cerebrum and a **smaller caudal cavity** for the cerebellum by the tentorium cerebelli. The brain of the domestic mammals is relatively small compared to the size of the head. It is located between a transverse plane drawn through the caudal rim of the orbit rostrally and a transverse plane drawn at the level of the external ear caudally. In the domestic mammals, the cerebellum is located ventral to the squamous part of the occipital bone.

In the ox and pig, the roof of the skull is pneumatized by parts of the extensive frontal sinus. Thus, the cerebrum is located deeper and further away from the external lamina of the skull. In small ruminants, cats and brachycephalic dogs the cerebral hemispheres are located superficially in the frontal and parietal part of the skull.

Rhombencephalon

Myelencephalon

The myeloencephalon comprises the medulla oblongata (Fig. 14-11), that encloses the caudal part of the fourth ventricle of the brain and the caudal medullary velum dorsally.

Medulla oblongata

The medulla oblongata is continuous with the spinal cord, the border between the two is arbitrarily defined as the transverse plane just rostral to the first cervical nerves. It is located in the fossa medullae oblongata, dorsal to the basiocciput. Its rostral part is widened as the result of an **accumulation of nuclei** and the central canal of the spinal cord opens into the **fourth ventricle.** Consequently, the characteristic organisation of the grey matter in the spinal cord is lost and the columns are moved to the side and divided into singular nuclei of spherical or **cylindrical shape.** The sensory nuclei are located furthest laterally, the **motor nuclei** closest to the middle and the **vegetative, parasympathetic nuclei** between them.

The following nuclei are located within the medulla oblongata (Fig. 14-10, 12, 14 and 16):.

- Nuclei of cranial nerves VI to XII,
- Corresponding parasympathetic nuclei,
- Caudal part of the large nucleus of the trigeminal nerve.

It also comprises nuclei of the respiratory and circulatory centre, located close to the fourth ventricle within the reticular formation. The **ventral surface of the medulla oblongata** is divided into halves by the ventral median fissure continuous with that of the spinal cord and flanked by longitudinal

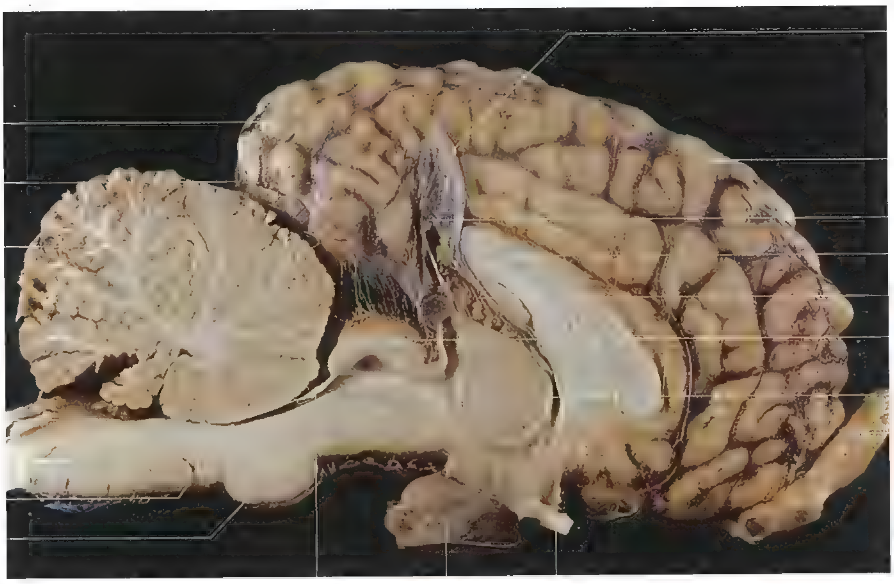


Fig. 14-11. Brain of a horse, median section (courtesy of Prof. Dr. Sabine Breit, Vienna).

ridges, the **pyramids** (Fig. 14-12 and 14). Each pyramid consists of myelinated axons, which originate from neuron cell bodies located in the cerebral cortex and extend to the medulla oblongata or the spinal cord. Most fibres cross the midline to form the **pyramidal decussation** (decussatio pyramidum) at the spinomedullary junction. The decussation of pyramidal fibres and other descending tracts explains why one side of the brain controls voluntary movement in the contralateral side of the body.

At the rostral end of the pyramids lies a flat band of transverse fibres, the **trapezoid body** (corpus trapezoideum), that ontogenetically belongs to the pons (Fig. 14-12).

The **abducent nerve** (VI) appears caudal to the pons at the lateral angle formed by the pons and the pyramids. The **hypoglossal nerve** (XII) emerges on the caudal end of the pyramids on their lateral aspect. The **facial** (VII) and the **vestibulocochlear** (VIII) nerves appear as lateral continuations of the trapezoid body. The **glossopharyngeal** (IX), **vagus** (X) and **accessory** (XI) arise from the lateral aspect of the medulla oblongata in close succession (Fig. 14-14 and 16).

The **accessory** nerve receives an additional spinal root from the cervical spinal cord. These fibres arise from the cervical spinal cord, pass cranially to unite with the fibres of the accessory nerve from the medulla oblongata (Fig. 14-16).

Dorsolateral to the pyramids at the caudal medulla oblongata is the **olivary eminence** that marks the **olivary nucleus** (nucleus olivaris). The olivary nucleus presents a distinctive serpentine profile and plays an important role in controlling **motor functions** of the body.

Ascending fibres constitute the **medial lemniscus,** which also passes through the medulla oblongata to reach the cerebellum via the caudal cerebellar peduncles.

Functions of the medulla oblongata

The medulla oblongata controls **respiration** and **circulation,** regulated by higher centres of the cortex. In addition, the nuclei for several reflexes for the protection of the eye (palpebral reflex, lacrimal secretion), the upper respiratory tract (sneezing and coughing), **food intake** (suckling, swallowing) are located within the medulla oblongata. Nerve fibres extending between the different nuclei form the basis of central reflex arcs. Lesions to the medulla oblongata result in deficits of the cranial nerves and may cause death in severe cases.

Metencephalon

The metencephalon constitutes the rostral part of the rhombencephalon. It can be divided into the following parts:

- Transverse pons,
- Cerebellum,
- Tegmentum of the metencephalon (tegmentum metencephali) and
- Rostral medullary velum (velum medullare rostrale).

Pons

The pons consists of a **ventral** and a **dorsal part;** the latter is designated the **tegmentum of the pons** (tegmentum pontis). The **ventral part** features transverse pontine fibres, that bulge out ventrally (Fig. 14-11, 12, 16 and 23). The ventral surface of the pons has sharp rostral and caudal demarcations.

The **trigeminal nerve** (V) emerges on the lateral aspect of the pons and its **motor nucleus** is located within the pons (Fig. 14-14). Several other nuclei are situated within the pons and are responsible for controlling motor functions of the body. Similar to the medulla oblongata, nuclei and nerve fibres of

Fig. 14-12. Brain of a dog, ventral aspect.

the reticular formation occupy up to half of the pons on transverse section. It has also a large number of ascending and descending nerve tracts, which proceed to the cerebellum as the middle cerebellar peduncle.

Cerebellum

The cerebellum constitutes the second largest part of the metencephalon and is located above the fourth ventricle. It is roughly globular and its surface features fissures, that divide the grey mass into **lobes,** and smaller fissures that further subdivide the mass into **small lobules** and these into smaller units known as **folia.** In the cerebellum the bulk of the grey matter forms the **cortex** (cortex cerebelli) and encloses the **white matter** or **medulla** (corpus medullare). The white matter arises from the **peduncles** and radiates through the various lobules, resembling a tree. Because of this appearance, it is often referred to as the **tree of life** (arbor vitae). Additional grey matter forms several nuclei, termed basal nuclei, embedded within the medulla (Fig. 14-11).

The cerebellum can be divided into the (Fig. 14-10, 11, 14 and 15):

- median sagittal ridge (vermis),
- lateral hemispheres (hemispheria cerebelli).

Based on the phylogenetic development, the **vermis** (Fig. 14-15) can be further subdivided into **rostral** (archicerebellum), **caudal** (neocerebellum) **lobes,** and the **flocculonodular lobe** (palaeocerebellum) caudoventrally.

The cerebellum is connected to the brainstem by **three peduncles** on each side. Rostrally it is attached to the rostral medullary velum by the **rostral cerebellar peduncles** (Fig. 14-11). The **caudal cerebellar peduncle** connects with the caudal medullary velum and the medulla oblongata. The **middle cerebellar** peduncles extend ventrolaterally to the pons. The functions of the cerebellum are reflected by its connections to other parts of the brain. The caudal peduncle is largely composed of afferent fibres with origins within the vestibular nuclei, the olivary nucleus and the reticular formation. The middle peduncle is also composed of afferent fibres, which arise from the pontine nuclei. The rostral peduncle is largely composed of efferent fibres dispatched towards the red nucleus of the midbrain, the reticular formation and thalamus. It also includes an afferent component from the spinal cord.

The **functions of the cerebellum** are concerned with **balance** and the **co-ordination of skeletal muscles** with regard to posture and locomotion. Balance is located in the flocculonodular lobe. The caudal lobe controls the **motor function,** the rostral lobe receives **proprioceptive information.** Deficits of cerebellar function, results in cerebellar ataxia, clinically apparent as loss of balance and coordination.

Medullary vela (vela medullaria) and rhomboid fossa (fossa rhomboidea)

The **rostral** and **caudal medullary vela** (velum medullare rostrale et caudale) are thin medullary membranes that extend between the rhomboid fossa and the cerebellum like a tent

Fig. 14-13. Brain of a dog, dorsal aspect.

(Fig. 14-11). Together with the cerebellum, they form the roof over the **fourth ventricle.** Closely related to the caudal medullary velum is the **tela choroidea** of the fourth ventricle.

The floor of the fourth ventricle is formed by the **rhomboid fossa** (Fig. 14-21). Gross visualisation of the rhomboid fossa requires the removal of the cerebellum and the medullary vela. Its rostral part belongs to the metencephalon, its caudal part to the **myelencephalon.** It has a median sulcus and a bilateral sulcus limitans, marking the transition from floor to wall. Rostrally the sulcus limitans ends in the locus caerulus, which is overlies the motor nucleus of the trigeminal nerve.

The walls of the rhomboid fossa are marked by a bilateral **eminence** (area acustica), that is formed by the underlying nuclei of the vestibulocochlear nerve. Another eminence is visible between the median sulcus and the sulcus limitans (eminentia medialis) marking the **nuclei of cranial nerves IX, X** and **XII.** The caudal end of the sulcus medianus is called **obex.**

Mesencephalon

The midbrain or mesencephalon can be divided into (Fig. 14-20):

- Tectum (tectum mesencephali), also termed tectal plate (lamina tecti) or quadrigeminal plate (lamina quadrigemina) dorsally,
- Tegmentum (tegmentum mesencepahli),
- Cerebral peduncles (crura cerebri, pedunculi cerebri) ventrally (Fig. 14-12, 14, 22 and 23).

The **midbrain** contains the **mesencephalic aqueduct,** a channel that extends between the fourth ventricle and the third ventricle (Fig. 14-20 and 22). It is covered by the **tectal plate,** that consists of paired caudal and rostral swellings, the colliculi, that serve as reflex centres for hearing and vision. The **rostral colliculi** are joined to the lateral geniculate bodies of the diencephalon and are relay centres upon the visual pathways. The **caudal colliculi** are joined by a substantial commissure and are connected with the medial geniculate bodies. They are relay centres upon auditory pathways (Fig. 14-18).

The **tegmentum constitutes** the core of the midbrain between the tectal plate and the cerebral peduncles. Much of it is formed by the **reticular formation** (Fig. 14-19). It contains the motor and parasympathetic nucleus of the **oculomotor nerve** (Fig. 14-14), the **trochlear nuclei** and the **red nucleus** (Nucleus ruber).

Part of the trigeminal nucleus also extends into the tegmentum (Fig. 14-14). The **substantia nigra** is a prominent lamina underlying the red nucleus that can be identified in cross sections by its darker colour.

The **cerebral peduncles** are visible on the ventral aspect of the brain caudal to the optic tract at the base of the brain. They are bound laterally by the piriform lobes and caudally by the pons (Fig. 14-14 and 16). They comprise of descending fibre tracts from the **telencephalon.**

The **crura cerebri,** flank the interpeduncular fossa, that contains the **mammillary body, hypophyseal infundibulum** and **pituitary gland.** The oculomotor nerve emerges on the ventromedial aspect of the cerebral peduncles. The **trochlear nerve** leaves the midbrain dorsally, just caudal to the tectal plate.

Fig. 14-14. Brain of a goat, ventral aspect (Schabel, 1984).

The **functions of the midbrain** are determined by the nuclei of the **third** and **fourth cranial nerves** and the reflex centres for hearing and vision. It plays an important role in co-ordination of **voluntary motor function,** controlled by higher centres. The red nucleus is important for **muscle tone, body posture** and **locomotion.** The substantia nigra is essential for the initial phase of fast movement.

Prosencephalon

Diencephalon

The diencephalon (Fig. 14-10) is only visible on the ventral surface of the brain, where parts of it protrude between the cerebral peduncles. Some textbooks classify the diencephalon as being the most rostral part of the brainstem. It can be divided into the following parts in dorsoventral sequence:

- Epithalamus,
- Thalamus,
- Metathalamus and
- Hypothalamus.

The **epithalamus** comprises the **pineal gland** (glandula pinealis, epiphysis cerebri) (Fig. 14-10 and 23) and the **habenula** with its associated tracts. The pineal gland is a small median body that projects dorsally. It is an **endocrine gland,** that secretes **melatonin** and other compounds, which affect sexual activity.

The **habenula** consists of habenular nuclei, which receive fibres from the telencephalon and send fibres to the mesencephalon. It is an important part of the **olfactory pathway.** The habenula of the left and right sides are connected by the habenular commissure.

The **thalamus** is the largest part of the diencephalon and can be further subdivided into the **dorsal thalamus** and the **subthalamus.** The dorsal thalamus is composed of a large number of nuclei through which input to the cerebral cortex is channelled, including sensory information from afferent tracts from **gustatory, optic, acoustic** and **vestibular organs** (except olfaction) (Fig. 14-18 and 19).

The **subthalamus** is the rostral continuation of the tegmentum of the mesencephalon. It contains the subthalamic nuclei that act as relay stations in the **extrapyramidal motor** pathway. The **left** and **right thalamus** is connected by the interthalamic adhesion, which is encircled by the **annular third ventricle** (Fig. 14-21). The **hypothalamus** (Fig. 14-22) forms the floor and the wall of the **third ventricle.** It consists of the **optic chiasm** rostrally, the **mammillary body** (Fig. 14-14) caudally and the grey tuber of the third ventricle **(tuber cinereum)** in between. The grey tuber gives rise to the infundibulum, which suspends the **hypophysis** (pituitary gland). The hypophysis consists of the **neurohypophysis,** the **adenohypophysis** and an **intermediate part.**

The **metathalamus** comprises the **medial and lateral geniculate bodies** (corpora geniculata), which have already been mentioned in the description of the midbrain. The fibres from the **optic tract** terminate in the lateral geniculate nucleus, which oc-

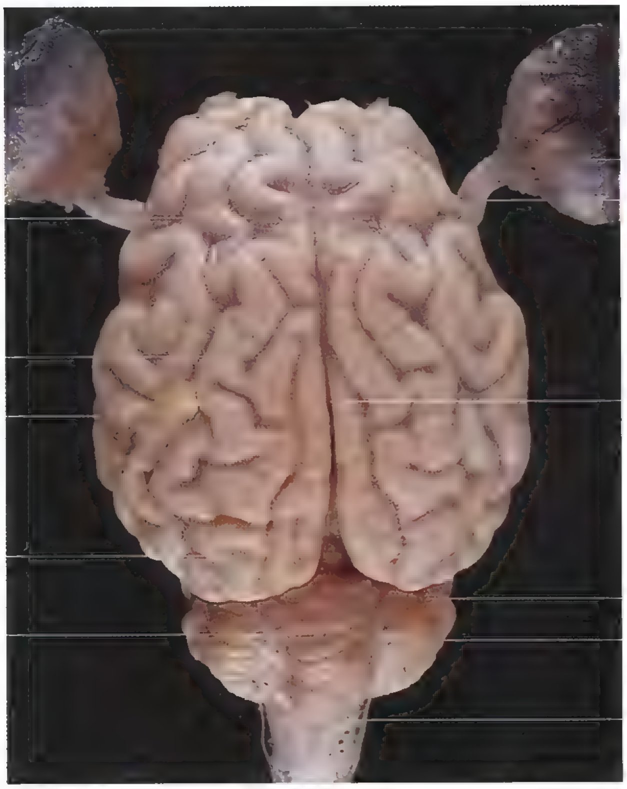


Fig. 14-15. Brain of a goat, dorsal aspect (Schabel, 1984).

cupies the like-named body. It sends fibres to the optic areas of the cortex. The medial geniculate nuclei receive acoustic fibres and relay acoustic information to the cerebral cortex.

Functions

The **pineal gland of the epithalamus** is an endocrine gland, which regulates sexual activity and its seasonal changes. It is also involved in the sleep-wakefulness cycle of the metabolism. The afferent nerve tracts of all sensory organs terminate within the thalamus. The thalamus channels input from the sensory organs (with the exception of the olfactory sense) to the cerebrum.

The **hypothalamus** controls the **hypophysis** and thus the endocrine system. It plays a major role in behaviour, including eating and drinking behaviour and regulates temperature and the autonomic nervous system.

Telencephalon

The telencephalon consists of the **paired cerebral hemispheres,** separated by the cerebral longitudinal fissure (Fig. 14-12 to 17). They are connected across the midline by commissural fibres that form the corpus callosum, rostral commissure and the dorsal and ventral commissures of the hippocampus. The **surface of the hemispheres** features elevated bands (gyri cerebri), called **gyri,** separated by grooves called **sulci** (sulci cerebri). Each hemisphere is composed of **surface grey matter,** designated **cerebral cortex** or **pallium,** underlying cerebral **white matter,** and deep accumulations of grey matter, generally referred to as basal nuclei. (Fig. 14-21).

The alternating presence of these nuclei with the afferent, efferent, association and commissural fibres of the white matter in which they are embedded give the region a striated appearance when sectioned. The term **striated body** (corpus striatum) is therefore applied to this region.

The **cortex or pallium** can be divided into three parts based on evolutionary history:

- Paleopallium,
- Archipallium and
- Neopallium.

The phylogenetically oldest part is the **paleopallium** and constitutes the ventral part of each hemisphere. It is primarily related to olfaction. The **archipallium,** the next oldest, forms the medial part of each hemisphere and extends from the longitudinal fissure into the hemisphere as the hippocampus (Fig. 14-20, 21 and 24). The **neopallium** is the youngest part and constitutes the predominant part of the cerebrum.

Today it is hypothesised, that the cortex is organised into **vertical columns,** that extend vertically through all the cortical layers with a diameter of 200–300 μm. Each column is related to a specific group of receptor cells in the periphery. Repeated stimuli to receptor cells results in the response of the same cortical cell. The human brain consists of about four millions of these columns with 2500 nerve cells each. However, these are functional units and can not be distinguished histologically.

Fig. 14-16. Brain of a horse, ventral aspect.

Rhinencephalon

The olfactory pathway begins with special afferent neurons in the olfactory mucosa. Bundles of nonmyelinated axons of these neurons constitute the **olfactory nerves,** and pass through the cribriform plate to terminate in the **olfactory bulb** (Fig. 14-25).

The **olfactory bulb** (bulbus olfactorius) forms the most rostral part of the rhinencephalon, located in the **ethmoidal fossa** (Fig. 14-14, 16 and 21). The rhinencephalon continues caudally with the **olfactory peduncle** (pedunculus olfactorius), that extends from the olfactory bulb to bifurcate into the medial and lateral olfactory tract. The olfactory tracts border a **triangular area** (trigonum olfactorium), that constitutes, together with the **rostral perforate substance** (substantia perforata rostralis), the olfactory area. The rostral perforated area is located caudal to the olfactory trigone and is perforated by numerous blood vessels.

The **larger lateral olfactory tract,** continues caudally as the **piriform lobe** (lobus piriformis), and forms a massive bulge, situated lateral to the hypothalamus (Fig. 14-21). Medially it is continuous with the hippocampus. Underlying the piriform lobe is the **amygdaloid body** (corpus amygdaloideum) (Fig. 14-21 and 24), which is composed of several nuclei.

Limbic system

The term limbic system is applied to a collection of brain structures involved with **emotional behaviour.** It consists of cortical and subcortical components (Fig. 14-24). The **cortical part** comprises interconnected telencephalic structures on the medial and basal aspect of the hemispheres, namely the cingulate gyri, the piriform lobe and the hippocampus. The **subcortical part** includes components of the diencephalon (habenula, hypothalamus, thalamus), midbrain (interpeduncular and tegmental nuclei) and the amygdaloid body.

The limbic system receives olfactory input from the piriform lobe that initiates mostly visceral motor activities, but also triggers emotional behaviour, such as fear, aggression and apparent pleasure. The limbic system has great input on thirst, hunger and sexual behaviour and is closely related to the reticular formation.

Neopallium and cerebral hemispheres

The neopallium constitutes the major part of the telencephalon, forming the dorsolateral part of each hemisphere, interposed between the ventral paleopallium and the medial archipallium. In the domestic mammals, its surface is marked by **cerebral convolutions** (gyri cerebri) and **grooves** (sulci cerebri), which can be used as anatomical landmarks.

Fig. 14-17. Brain of a horse, dorsal aspect.

The **deep longitudinal cerebral fissure,** which is flanked by the marginal and suprasylvian sulci, separates the **left** and **right hemisphere** (Fig. 14-17). The **cruciate sulcus** extends from the longitudinal cerebral fissure running transversely on the rostrodorsal aspect (Fig. 14-17). The **transverse cerebral fissure** separates the cerebrum from the cerebellum. The **lateral surface** of each hemisphere is marked by the pseudosylvian fissure in which the middle cerebral artery ascends. Rostral and caudal to the pseudosylvian fissure runs the rostral and the caudal ectosylvian sulci. The rhinal sulcus divides the neopallium from the rhinencephalon.

The **medial surface** features the splenial sulcus, which divides the **neopallium** from the **archipallium.** Caudodorsal to the splenial sulcus passes the ectosplenial sulcus. Close to the commissure of the cerebral hemispheres, is another sulcus (sulcus corporis callosi) and rostral to it the genual sulcus (Fig. 14-20, 22 and 23).

To facilitate description the neopallium can be divided into lobes named according to the overlying bones. These are the **frontal,** the **parietal,** the **temporal** and the **occipital lobes** (Fig. 14-13, 15 and 17). Motor areas are located mostly in the frontal lobe, which give origin to the pyramidal tracts. The parietal lobe features mainly sensory areas, the temporal lobe includes the auditory area and the occipital lobe the visual area.

Internal organisation of the hemispheres

The accumulations of grey matter, embedded within white matter are generally known as **corpus striatum** (formerly designated basal or stem ganglia) (Fig. 14-19, 21, 24 and 26).

The corpus striatum includes the following structures:

- Caudate nucleus (nucleus caudatus),
- Putamen,
- Claustrum and
- Amygdaloid body (corpus amygdaloideum).

The **caudate nucleus** protrudes at the rostral part on the floor of the **lateral ventricle** (Fig. 14-18 to 22). Lateroventral to the caudate nucleus is the **putamen,** separated by fibres of the **internal capsule** (capsula interna). Adjacent to the lateral aspect of the putamen lies the **claustrum,** a narrow band of grey sustance (Fig. 14-19 and 26). Between the putamen and the claustrum, pass the fibres of the **external capsule** (capsula externa). A thin band of white substance (capsula extrema) separates the claustrum from adjacent cerebral cortex.

The function of the claustrum is not well understood, but it has connections with the visual system and the limbic system.

The other nuclei are principally concerned with voluntary posture and movement. The corpus striatum is responsible for producing appropriate direction and magnitude of move-

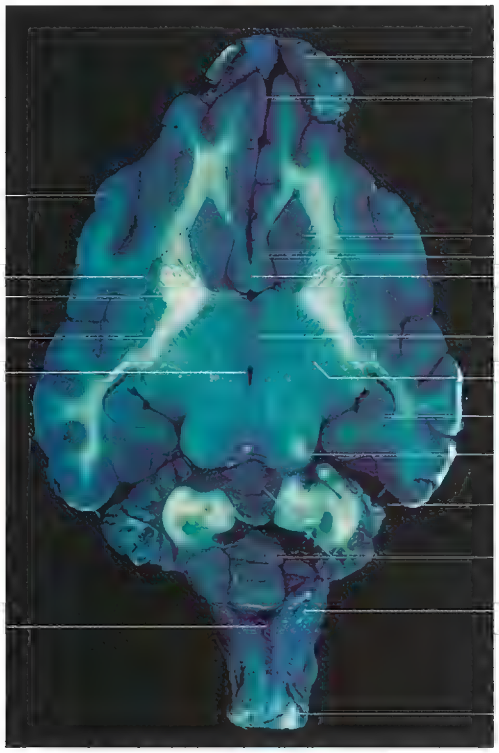


Fig. 14-18. Horizontal section of the brain of a dog at the level of the interventricular foramen.

Fig. 14-19. Horizontal section of the brain of a dog at the level of the rostral commissure.

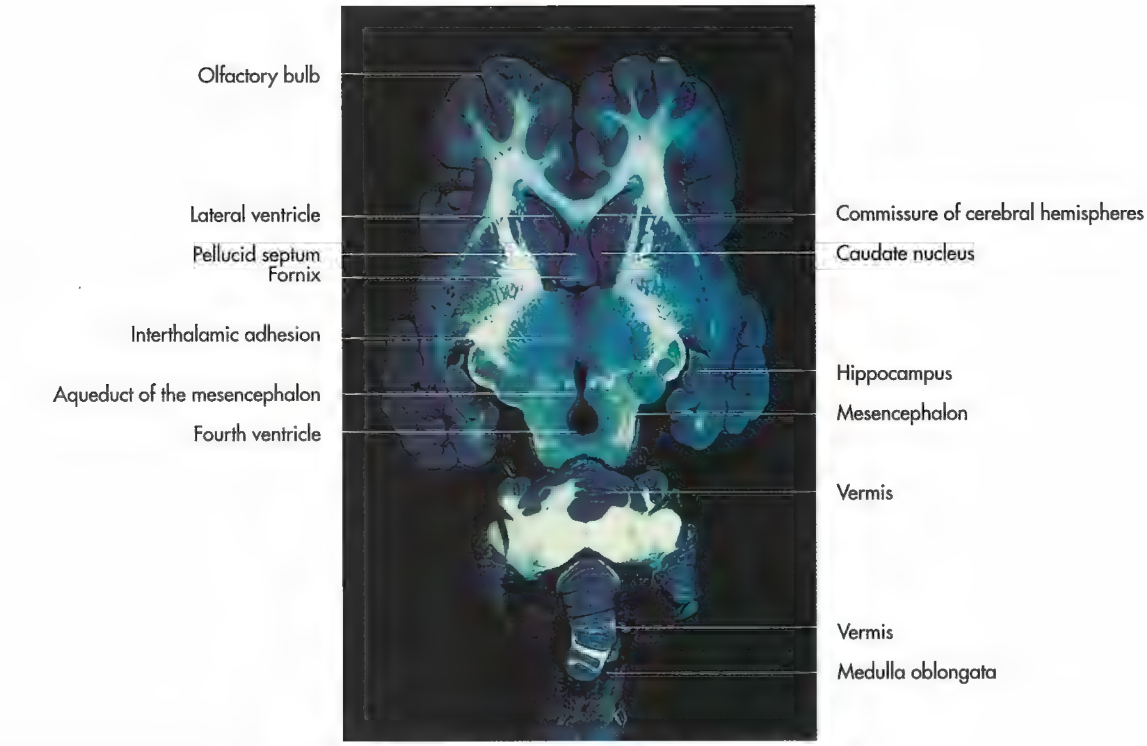


Fig. 14-20. Horizontal section of the brain of a horse at the level of the interthalamic adhesion.

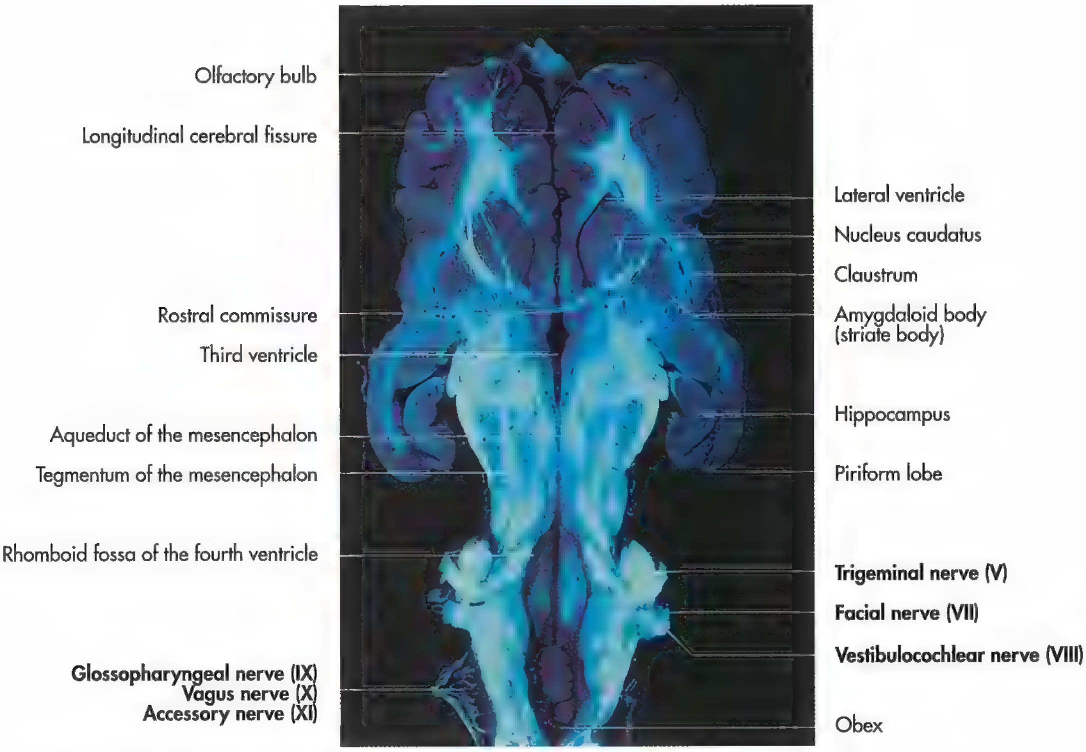


Fig. 14-21. Horizontal section of the brain of a horse at the level of the mesencephalic aqueduct.

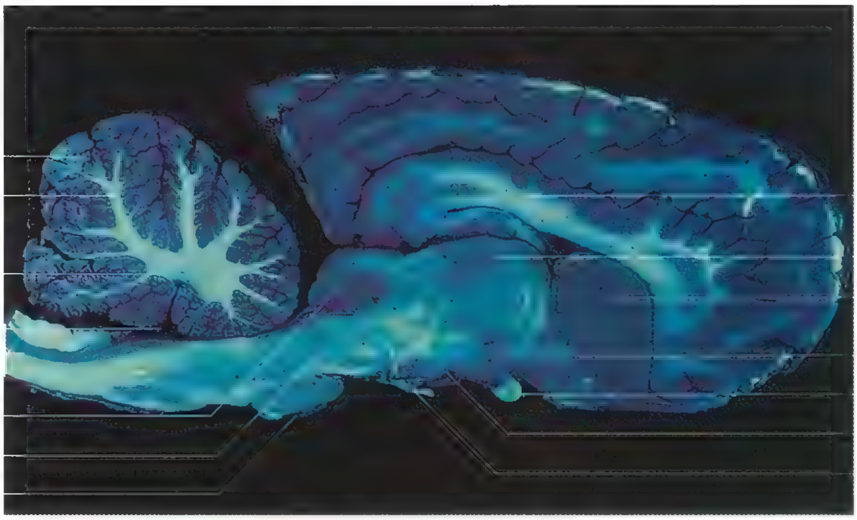


Fig. 14-22. Paramedian section of the brain of a horse.

ment by selective inhibition of motor output.The white matter of the cerebrum consists of ascending and descending nerve fibres: the association, projection and commissural fibres.

Projection fibres either leave or enter the hemispheres from or to lower parts of the central nervous system. These fibres traverse a band of white substance termed **internal capsule** (capsula interna). Association fibres connect cortical regions within the same hemisphere. They range in extent from those that connect adjacent gyri to those that travel over longer distances.

Commissural fibres connect corresponding regions of the two hemispheres. The bulk of these fibres decussate in the corpus callosum (Fig. 14-20, 22 and 23). The rostral commissure connects the two rhinal lobes and the amygdaloid body.

The **caudal commissure** (commissura fornicis seu hippocampi) is situated ventral to the splenium of the corpus callosum. The corpus callosum enables the two hemispheres to function coherently as a single cognitive centre.

On dissection, it consists of an **elongated region** (truncus corpori callosi) that has a **rounded caudal end** (splenium) and **rostral end** (genu corporis callosi). A thin membrane extends between and ventral to the corpus callosum and the fornix, the **septum pellucidum,** which separates the two lateral ventricles (Fig. 14-23).

Functions of the telencephalon

The **cerebral cortex** can be divided into areas based on their function, which in turn are determined by their neural connections. The **somesthetic area** receives tactile and kinaesthetic input from the skin. It is located in the caudal half of the postcruciate gyrus and the rostral suprasylvian gyrus. This area can be subdivided into the parts that receive information from the contralateral half of the body only (area sensorica contralateralis) and parts that receive information of both body halves (area sensorica bilateralis). The latter are located in the ectosylvian gyrus. Adjacent to the somesthetic cortex is the gustatory area for the tongue and pharynx.

The **olfactory area** is located within the rhinencephalon and is described earlier in this chapter. The **visual area** (area optica) extends over the medial and part of the dorsolateral surface of the occipital lobe. The **auditory area** is located predominantly in the rostral sylvian gyrus, the **vestibular area** is adjacent to it.

The **motor area** of the cerebral cortex (area motorica) is located rostral to the somesthetic area. It is located in the rostral half of the postcruciate gyrus, in the coronal gyrus, and in the ventrolateral part of the praecruciate gyrus up to the praesylvian sulcus. The motor area gives rise to corticospinal, corticonulcear and corticoreticular projection fibres for the control of voluntary posture and movement.

The motor area of humans contains so-called Betz giant pyramid cells, which form the longest and thickest axons extending from the cortex to the sacral spinal cord.

The **association cortex,** which has connections only within the cerebral cortex and is thought to be responsible for **intelligence.** It receives input from the sensory areas it surrounds and functions to interpret the information provided. The hippocampus, a gyrus of the archipallium folded inward deep to the piriform lobe, influences endocrine, visceral and emotional activity via its connections to the hypothalamus, the septum pellucidum and the gyrus cinguli. In humans, it plays an important role in the process of learning and memory.

Pathways of the central nervous system

Pathways of the central nervous system cannot be visualised anatomically, but are **functional units,** that consist of ascending or descending axons travelling together and conveying information from one location to another. Their function and location have been determined by assessing the results of experimentally induced damage to certain parts of the central nervous system. The following section will deal only with fundamental, relatively discrete structured pathways. For a more detailed description, readers should refer to textbooks of neurophysiology and neuropathology.

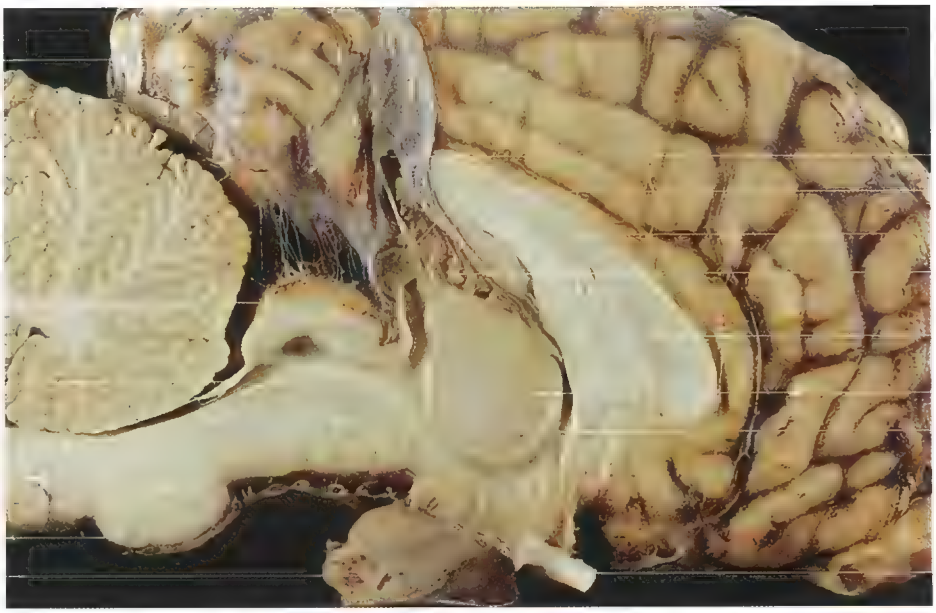


Fig. 14-23. Brain of a horse, median section (courtesy of Prof. Dr. Sabine Breit, Vienna).

Ascending pathways

General somatic afferent pathways

General somatic afferent pathways convey information from various types of receptors within the skin and deeper somatic tissues to the brain. This information includes a variety of sensory modalities: touch, pressure, vibratory sensation, thermal sensation, pain and kinaesthetic sensation relating to joint angulation and muscle tension.

The primary neurons concerned with these senses are located within the dorsal root ganglia of the spinal nerves and the corresponding ganglion of the trigeminal nerve for the head. The ascending pathways of this group can be divided into the:

- Medial lemniscus,
- Extra-lemniscal system.

The **medial lemniscus** includes the most important ascending tracts (Fig. 14-28). It can be subdivided into the **spinal lemniscus** for the trunk and limbs and the **trigeminal lemniscus** for the sensory nerve fibres from the head. The sensory neurons of the spinal lemniscus run in the dorsal funiculus of the spinal cord. Those arising from the lumbosacral plexus and the more caudal part of the trunk occupy the **medial positions** (Goll's column, fasciculus gracilis). Those from the brachial plexus and the cranial part of the trunk assume more **lateral positions** (cuneate fascicle, fasciculus cuneatus).

Both tracts end in the like-named nuclei **(nucleus cuneatus, nucleus gracilis)** of the dorsal part of the medulla oblongata. After synapsing, the axons of the second stage neurons decussate to the opposite side to reach the caudoventral nuclear complex of the thalamus, where they again synapse. The tertiary axons project to the somesthetic area of the cerebral cortex. In its course through the brainstem, the medial lemniscus is joined by fibres from the sensory nucleus of the trigeminal nerve following decussation within the pons.

The **extra-lemniscal system** forms a second, **spinothalamic tract,** which conveys impulses, that are characterised by slower propagation and less precise localisation of the originating stimuli compared to the medial lemniscus. The primary axons terminate in neurons of the dorsal horns close to their spinal root. After forming synapses with several interneurons, the second stage neurons then pass into the white matter, where they travel cranially in the ventrolateral funiculi of the white matter to synapse in the thalamus. The tertiary neurons project from the thalamus upon a cortical area rostral to that of the lemniscal system.

Information of **proprioceptive nature** from receptors within tendons and muscles do not reach conscious perception. The primary axons terminate on dorsal horn cells and reach the cerebellum via the dorsal and ventral spinocerebellar tracts.

Afferent pathways of the sense organs

Visual pathways

The retina contains the receptors for **visual information.** The information is then conveyed to the brain by the optic nerve. The optic nerve of each eye converges to meet in the **optic chiasm** on the ventral surface of the brain, where some of the fibres decussate (Fig. 14-29). The proportion of fibres that are exchanged with the opposing optic nerve is correlated with the degree of binocular vision enjoyed by the species. In most birds, in which vision is essentially monocular, all fibres decussate. In the dog and cat, which have a better binocular vision, approximately 75% of the optic nerve fibres decussate to join the contralateral optic tract, caudal to the optic chiasm. In primates, in which binocular vision is best developed, approximately 50% of the fibres decussate.

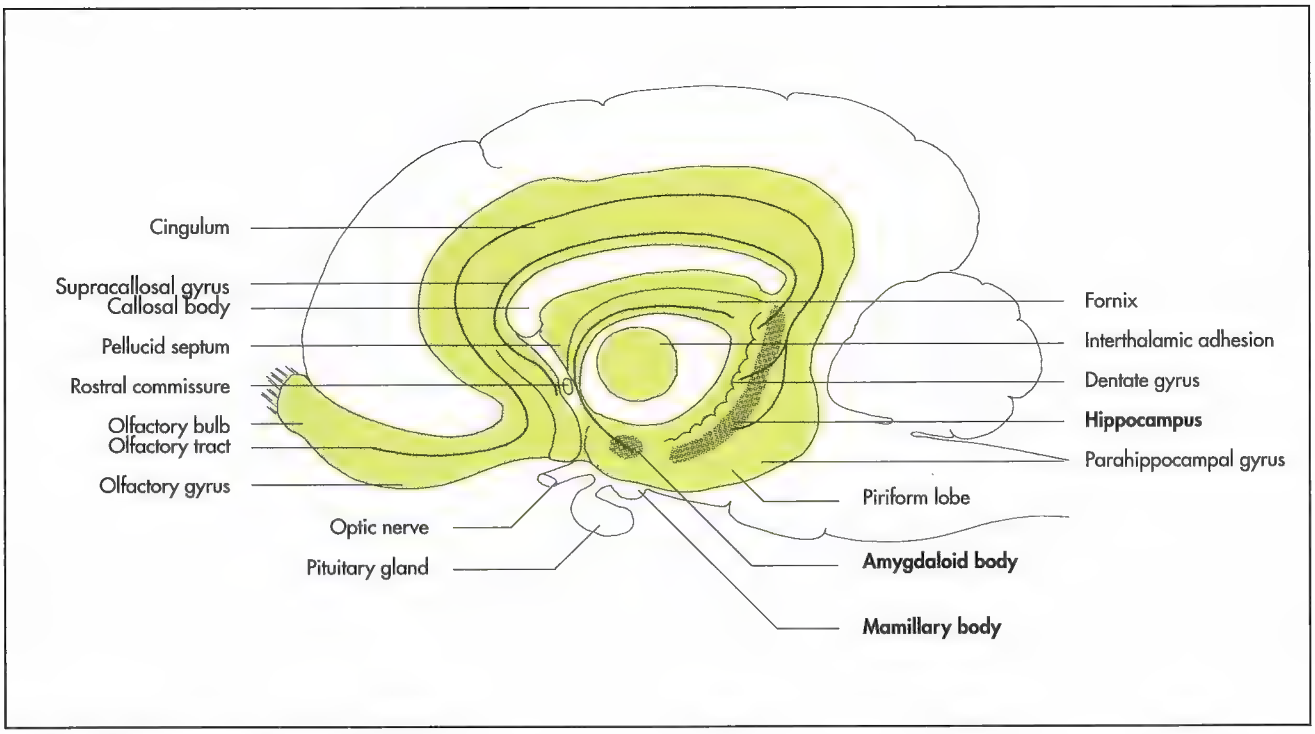


Fig. 14-24. Limbic system, schematic.

After the optic chiasm, the fibres continue as the **optic tract** (tractus opticus), which synapses in the lateral geniculate nucleus and in the **optic thalamus.** From the thalamus second stage neurons project, via the optic radiation of the **internal capsule,** on the **visual cortex** located within the occipital lobe of each hemisphere. This is the seat of conscious visual perception. Some fibres leave the optic tract to terminate in the **rostral colliculi of the midbrain,** in nuclei of the reticular formation and the **caudate nucleus.** These fibres are responsible for optic reflexes, such as the pupillary light reflex and accommodation.

Vestibular and auditory pathways

The receptor organs of balance and hearing are the **spiral organ,** the **semicircular ducts,** the **utricle** and **the saccule** of the **inner ear.** The primary neurons concerned with these senses are located within the spiral ganglion of the cochlea and the dorsal and ventral **vestibular ganglion** in the internal acoustic meatus (Fig. 14-30).

The fibres of both sense organs enter the brainstem within the **common vestibulocochlear nerve,** which pass into the **trapezoid body.**

Parts of the vestibular fibres terminate in the vestibular nuclei from which second stage neurons pass to the **cerebellum.** Some vestibular fibres bypass the vestibular nuclei and reach the cerebellum directly via the **caudal cerebral peduncles.** There are also neurons that descend from the vestibular nuclei to the motor neurons in the ventral horn of the spinal cord and to nuclei of cranial nerves III, IV and VI, which innervate the external ocular muscles. The fibres that lead to conscious perception of vestibular stimuli project on the cerebral cortex in the **temporal lobe via the thalamus.**

The **cochlear fibres** also enter the brainstem through the trapezoid body before they form synapses within the **dorsal** and **ventral cochlear nuclei.** Axons from nuclei of the trapezoid body and from cochlear nuclei ascend in the **lateral lemniscus** to the **caudal colliculi** of the midbrain. Axons of the cochlear nuclei project to both sides of the brain, however the majority decussate. Some fibres, responsible for the conscious perception of sound, synapse in the **medial geniculate nucleus** before projecting on the **auditory cortex within the temporal lobe.**

Descending pathways

Somatic motor pathways

Contraction of skeletal musculature is regulated by two systems of neurons, located at different sites of the central nervous system. These are the:

- Lower motor neurons,
- Upper motor neurons.

The **lower motor neurons** are located within the **ventral column of the grey matter** of the spinal cord and within the **motor nuclei of the cranial nerves** with a motor component. Lower motor neurons provide the efferent part of simple reflexes, but are principally controlled by the upper motor neurons. Their axons pass to the effector muscles within spinal or cranial nerves. The majority of the upper motor neurons are

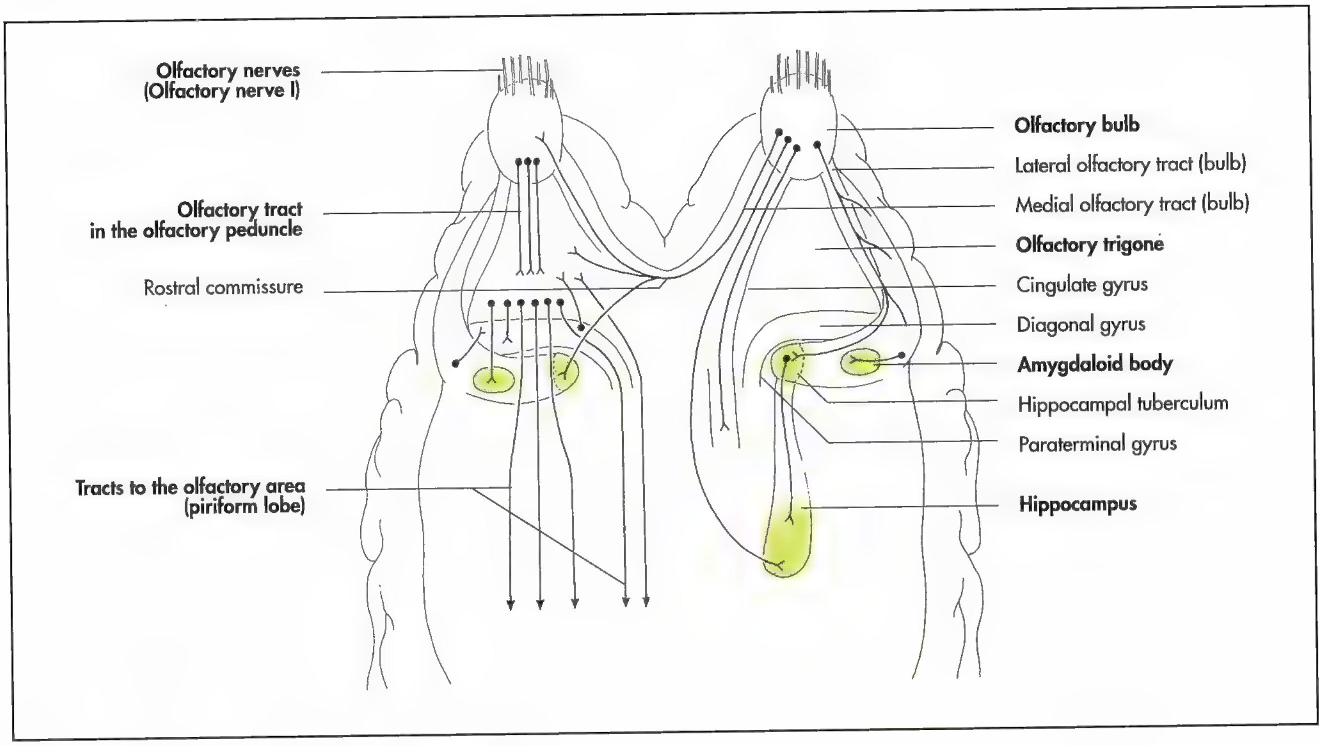


Fig. 14-25. Olfactory pathways, schematic (Najbrt, 1982).

located within the **neopallium,** some in the **red nucleus** of the mesencephalon and some in the reticular formation.

The **upper motor neurons** do not project directly upon muscle fibres, but regulate the activity of lower motor neurons by **excitation** or **inhibition.** The connections of the upper with the lower motor neurons are grouped in two descending pathways: the **pyramidal** and the **extrapyramidal system.** The pyramidal system is concerned with finely adjusted movements, while the extrapyramidal system controls coarser and stereotype movements, although the two work in close collaboration.

Fig. 14-26. Left half of the brain of a goat, horizontal section.

Pyramidal system

The development and organisation of the pyramidal system varies considerably among species. It is most developed in primates, in which severe damage results in permanent paralysis of the skeletal musculature of the contralateral side. In general, domestic mammals recover at least partially from similar injuries.

The **fibres of the pyramidal system** take origin from the giant Betz pyramidal cells of the **motor cortex of the neopallium.** They form an important fraction of the internal capsule on the lateral aspect of the thalamus before they traverse the ventral portion of the pons and enter the crus cerebri, on the ventral surface of the brain. They reappear on the surface as the **pyramids of the medulla oblongata.** The pyramidal system comprises three types of fibres:

- **corticospinal fibres,** that extend from the cerebral cortex into the spinal cord,
- **corticobulbar fibres,** that terminate in various nuclei of contralateral cranial nerves and
- **corticopontine fibres,** that pass to nuclei in the pons.

While some corticospinal fibres decussate within the medulla oblongata, others continue on their side of origin and cross over to the other side close to their terminations.

The fraction of fibres that decussate within the medulla oblongata varies among species. Almost all fibres decussate in the dog and cat, compared to 50% in ungulates. The extent of the fibres also varies. In carnivores, pyramidal fibres reach all levels of the spinal cord, while in ungulates the pyramidal system has terminated by the level of origin of the brachial plexus.

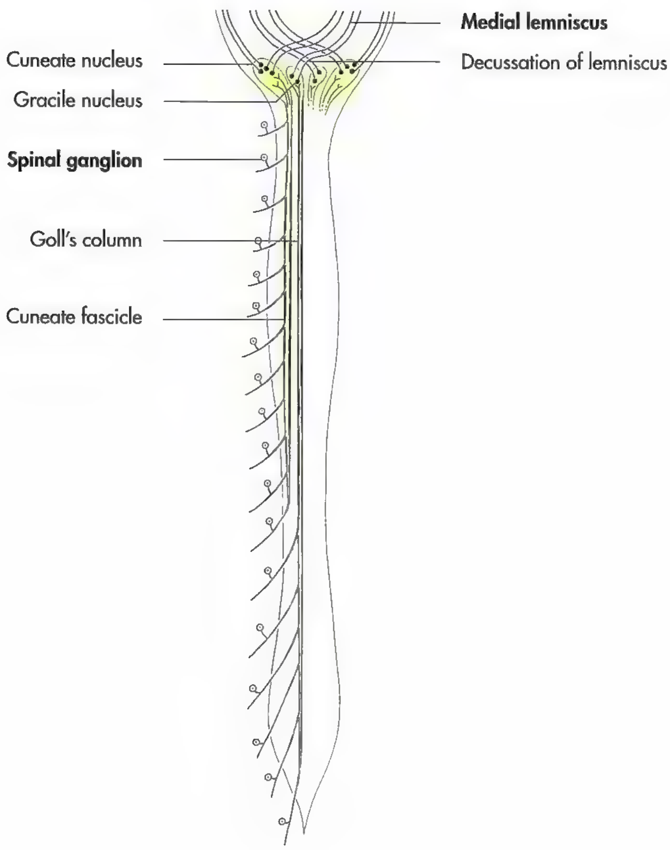


Fig. 14-27. Ascending pathways, schematic (Najbrt, 1982).

Extrapyramidal system

In contrast to the pyramidal system, the extrapyramidal system comprises various **multisynaptic pathways,** which originate from the corpus striatum, subthalamic nuclei, the substantia nigra, the red nucleus and the reticular formation. Interconnected with these nuclei are several motor centres, such as the thalamic nuclei, the vestibular nuclei, the reticular formation and the cerebellum to which all of the nuclei of the system project.

The **extrapyramidal system** is concerned with the maintenance of posture and with the execution of intended **movements,** by ensuring co-ordinated **muscle activity.** Numerous feedback circuits maintain the necessary balance between the inhibitory and excitatory parts of the extrapyramidal system. The **cerebellum** controls both the extrapyramidal and pyramidal systems. This is modified by afferent information from these two systems, as well as the vestibular apparatus. The information is utilised to control red and thalamic nuclei, the reticular formation and the vestibular nuclei.

The central autonomic nervous system

The autonomic (also called **visceral, vegetative** or idiotrop) nervous system is concerned with the co-ordination of function of the **inner organs** essential for life. It regulates respiration, circulation, digestion, metabolism, body temperature, water and electrolyte balance, reproduction and many more body functions. Most of the mechanisms that fulfil these functions also occur in the unconscious animal, e.g. during sleep or under general anaesthesia. Hence the term **"autonomic".**

The chief integration centre of the **autonomic nervous system** is the **hypothalamus.** It regulates activity through both neural and endocrine mechanisms. The neural pathways extend, either directly or via multisynaptic pathways through the reticular formation, from the hypothalamus to the autonomic nuclei of the brain stem or spinal cord. The **hypothalamus** receives information about visceral functions from almost all parts of the body via the mesencephalic nuclei, the reticular formation and the telencephalic parts of the limbic system. The **endocrine pathways** operate through **neurosecretory cells,** whose products are transported with the blood stream to the effector organs, where they act directly or are

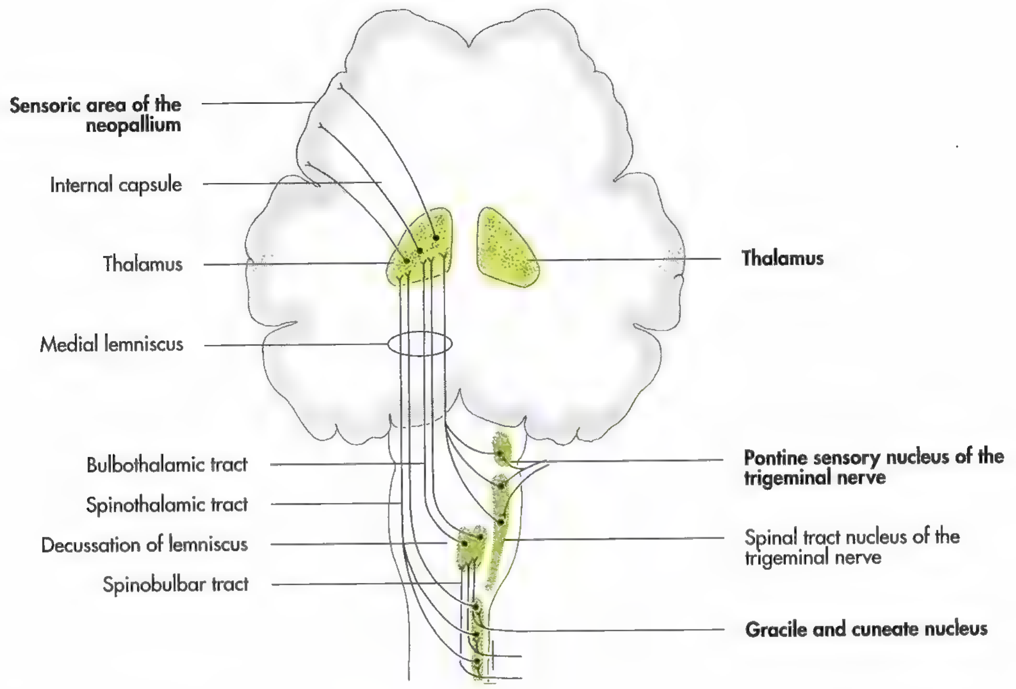


Fig. 14-28. Medial lemniscal system, schematic (Najbrt, 1982).

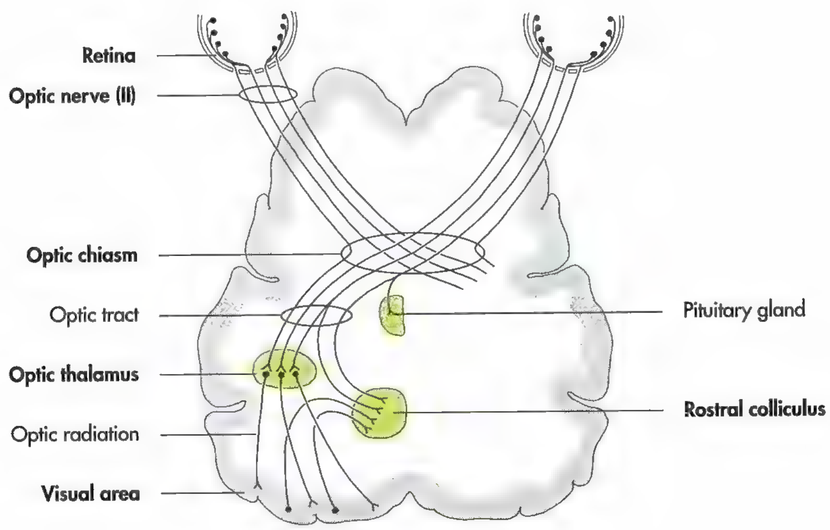


Fig. 14-29. Visual pathways, schematic (Najbrt, 1982).

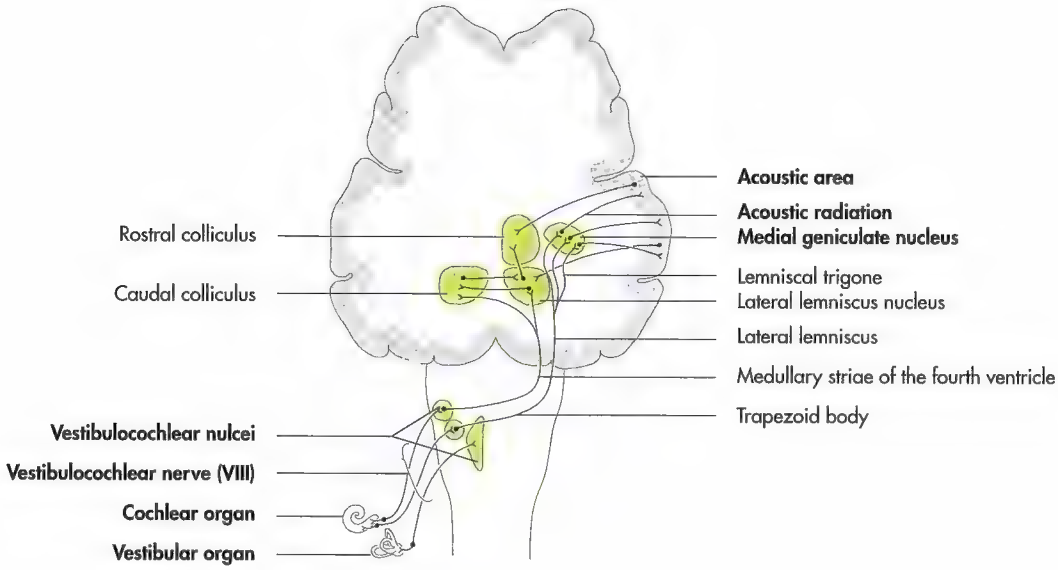


Fig. 14-30. Vestibular and auditory pathways, schematic (Najbrt, 1982).

conveyed to the hypophysis by portal vessels, where they initiate the release of hormones.

The **hypophysis** or **pituitary gland** is suspended below the hypothalamus by the infundibulum. Its caudal part, the neurohypophysis stores and releases hormones that are produced by neurosecretory cells within the **supraoptic** and **paraventricular nuclei** of the hypothalamus (Fig. 14-33) and transported along the axons of the cells.

The **adenohypophysis** receives neurosecretions from the hypothalamus via **hypophyseal portal vessels.** Feedback circuits regulate the interaction between the hypothalamus and the hypophysis. (For a more detailed description see chapter 15, "Endocrine organs".

Visceral pathways

The visceral pathways can be divided into **afferent** and **efferent pathways** and the latter can be further subdivided into **sympathetic** and **parasympathetic pathways.**

The receptor system of the **visceral afferent pathways** consists of mechanoreceptors and chemoreceptors, which are located within the inner organs and blood vessels. The cell bodies of the primary neurons are found within the dorsal ganglia of the spinal nerves and the corresponding ganglia of certain cranial nerves. Ascending autonomic pathways follow the lemniscal and the extralemniscal system to terminate within the thalamus.

Although most visceral activity occurs without conscious awareness, some projections to the cerebral cortex give rise to conscious perception, such as hunger, the sense of fullness of the rectum or the bladder. Pain arising from diseased inner organs may be confused with pain arising from the surface of the body, due to the exchange of information between the afferent visceral pathway and the cutaneous somatic pathway. Each organ has its **own reflection area,** called **head zone,** on the body surface, which in turn can be used to relieve pain of visceral origin (massage, acupuncture). Similar reflex points on the skin exist for the skeletal system (joints, spine).

The **efferent visceral pathways** can be grouped anatomically, pharmacologically and functionally in two systems: the **parasympathetic** and **sympathetic systems.** Both systems have two neurons per pathway, meaning that two successive neurons link the central nervous system to the structure innervated.

The **body of the first neuron** of each pair is located within the central nervous system and sends its myelinated axon out as part of the peripheral nervous system. The axon of this **preganglionic neuron** terminates in a peripheral ganglion, where it synapses with the postganglionic neuron of the chain, that end on the structure innervated (e.g. glandular, cardiac or smooth muscle cells). The preganglionic neurons of the sympathetic division are situated within the lateral column of the spinal cord between the first thoracic and the middle lumbar segments. Their axons synapse with the **postganglionic neurons** relatively close to the spinal cord in the **paravertebral ganglia** of the **sympathetic chain** or in the subvertebral ganglia on the aorta. Stimulation of the sympathetic pathways results in an increase in blood pressure, heart rate and respiratory rate, dilatation of the pupils, while at the same time gut motility and intestinal gland activity are decreased.

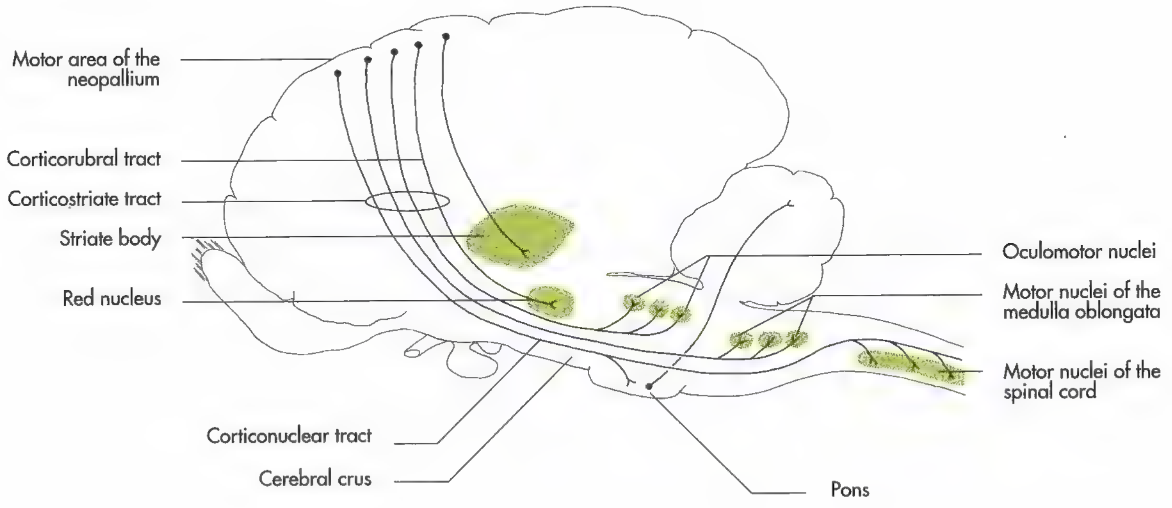


Fig. 14-31. Pyramidal system, schematic (Najbrt, 1982).

The **preganglionic neurons of the parasympathetic** division are located within nuclei of the oculomotor, intermediofacial, glossopharyngeal and vagus nerves within the brainstem and within the lateral columns of the sacral spinal cord. The bodies of the **postganglionic neurons** are found in smaller ganglia close, or actually incorporated within the organ innervated. The **ganglia of the head** have usually names, indicating their location (ciliary ganglion, pterygopalatine ganglion, otic ganglion, mandibular ganglion). Parasympathetic activity causes stimulation of gut motility, intestinal secretion, defecation and micturition, depression of heart and respiratory rate and constriction of the pupils.

The chief control centre of the visceral efferent pathways is the **hypothalamus** (Fig. 14-33). The rostral part of the hypothalamus is responsible for the parasympathetic division, while the caudal part controls the sympathetic division.

Meninges of the central nervous system

The central nervous system is enclosed by soft tissue membranes, termed meninges, which can be differentiated into three different layers:

- Dura mater,
- Arachnoid membrane,
- Pia mater.

Arachnoid membrane and **Pia mater** are collectively designated the **leptomeninges** because they are relatively delicate compared to the thick and fibrous dura mater. The **dura mater** is the most superficial layer, followed by the arachnoid membrane and the pia mater as the deepest layer.

The meninges exhibit certain topographical differences and are therefore described separately for their cranial and vertebral part (Fig. 14-34 to 39). The **meninges** are richly innervated and very sensitive with regards to pain, unlike the neural tissue they surround (brain tumours are normally not painful).

Spinal dura mater (dura mater spinalis)

The spinal dura mater is separated from the periosteum, lining the vertebral canal **(endorrhachis)** by the **epidural space** (cavum epidurale) (Fig. 14-38). The epidural space is filled with fat and contains a large venous plexus. As spinal roots traverse the vertebral canal, they are enclosed by meningeal sheaths. **Regional anaesthesia** can be performed by injecting an anaesthetic into the epidural space between the last lumbar and the **first sacral vertebra** (spatium lumbosacrale) or between the **last sacral vertebra** and the **first caudal vertebra.**

The caudal end of the dura mater forms a blind-ending sac and unites with the other meningeal layers to form a **fibrous strang** (filum terminale durae matris), that fuses with the dorsal surface of the caudal vertebrae. It is continuous with the cranial dura mater at the foramen magnum. The spinal dura mater is vascularised by spinal arteries.

Cranial dura mater (dura mater encephali)

The cranial dura mater is fused with the inner periosteum of the skull bones (Fig. 14-38). In addition to lining the cavity,

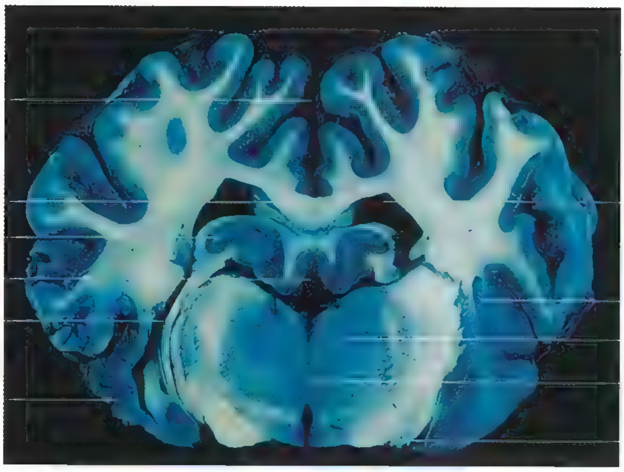


Fig. 14-32. Transverse section of the brain of a horse at the level of the interthalamic adhesion.

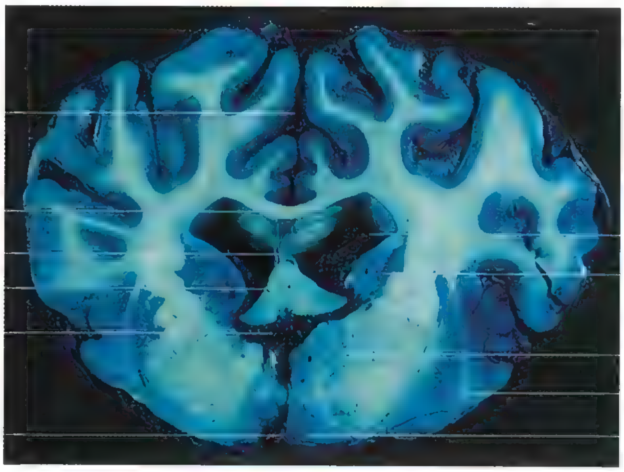


Fig. 14-33. Transverse section of the brain of an ox at the level of the rostral part of the diencephalon.

the dura mater forms partitions that project inward. The **cerebral falx** (falx cerebri) extends from the crista galli to the internal occipital protuberance and projects into the longitudinal fissure between the two hemispheres. Caudally the cerebral falx meets the **transverse tentorium cerebelli,** which separates the cerebellum from the cerebrum (Fig. 14-37). The median part of the tentorium cerebelli is osseous, but the dura mater encloses the bone and extends beyond it. The free edge of the **membranous tentorium cerebelli** borders the tentorial notch through which the brain stem passes. A third partition, the diaphragma sellae forms the roof of the hypophyseal fossa in which the hypophysis is located, forming a diaphragm around the infundibular stalk (Fig. 14-36). **Large venous sinuses** (sinus durae matris) are present within these dural projections (Fig. 14-36 and 38).

Like the spinal nerves, the **cranial nerves** are surrounded by dural sheaths until they leave the cranial cavity. Together with the leptomeninges they form cuffs that are surrounded by **cerebrospinal fluid.** At these sites, cerebrospinal fluid can enter perineural lymph vessels and diseases can spread from the lymphatic system into the meninges and neural tissue. The cranial dura mater is vascularised by the meningeal arteries.

Arachnoid membrane (arachnoidea)

The outer part of the arachnoid membrane consists of a continuous membrane moulded against the **dura mater.** Some authors describe a capillary space, the subdural space, between the dura mater and the arachnoid membrane, while others believe it to be an artefact not present in the living animal.

The second continuous cell layer of the arachnoid membrane is moulded against the **pia mater.** Between the two membranes, numerous trabeculae and filaments extend, which form a network of communicating chambers. This space is termed **subarachnoid space** (cavum subarachnoideale) and filled with **cerebrospinal fluid.** The depth of the sub-arachnoid space is variable, since the arachnoid mem-

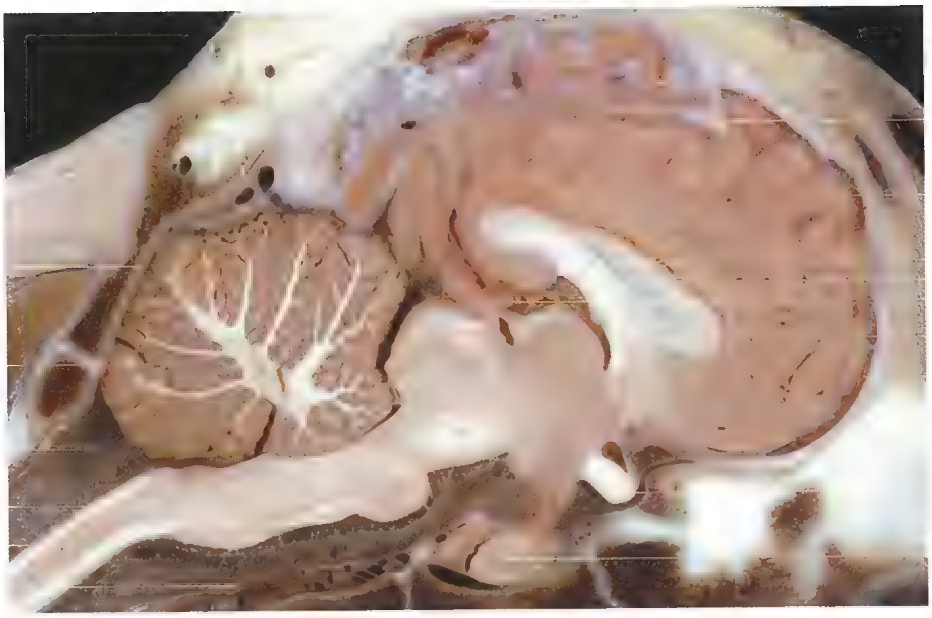


Fig. 14-34. Paramedian section of the brain of a calf with meninges and the beginning of the spinal cord.

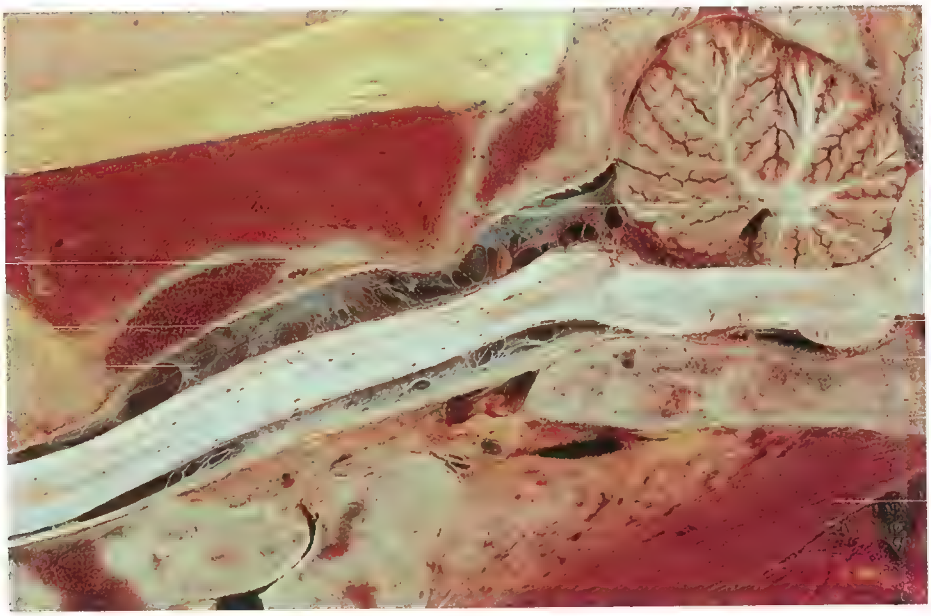


Fig. 14-35. Paramedian section of the brainstem and spinal medulla of a horse (courtesy of Dr. Gollob-Kammerer, Vienna).

brane stays in close contact with the dura mater, while the pia mater follows the surface of the brain.

At certain sites the subarachnoid space is enlarged to from so-called **cisternae,** which can be used to extract cerebrospinal fluid or for injection. Of great importance is the cerebellomedullary cistern, which is located where the caudal surface of the cerebellum meets the dorsal surface of the medulla oblongata. It is a common site for obtaining cerebrospinal fluid and can be reached by passing a needle between the atlas and the skull. An alternative site is the lumbosacral space or the space between the sacrum and the first caudal vertebra. Large, mushroom shaped projections extend from the **arachnoid membrane** (granulationes arachnoidales, Pacchioni-granulations) into dural venous sinuses. It is hypothesised that in these areas cerebrospinal fluid can enter the general circulation. These arachnoidal villi are not present in the sheep.

Fig. 14-36. Dura mater at the base of the cranium of a goat, dorsal aspect (Schabel, 1984).

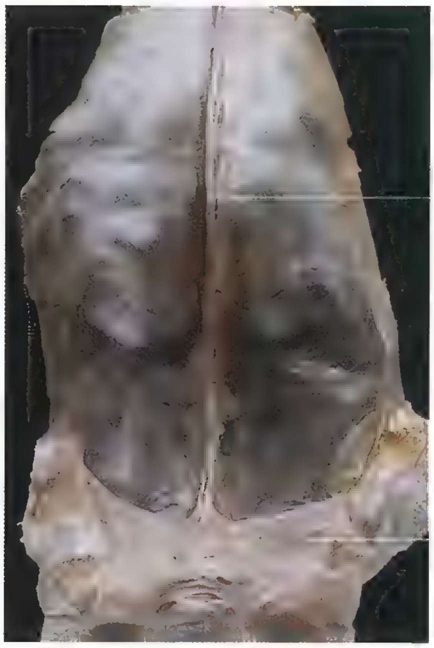


Fig. 14-37. Dorsal dura mater of the brain of a goat, ventral aspect (Schabel, 1984).

Cerebral and spinal pia mater (pia mater encephali et spinalis)

The pia mater is in direct contact with the **glial limiting membrane of the neural tissue** (Fig. 14-38 and 39). The pia mater is richly innervated and receives a generous blood supply from which several blood vessels extend into the neural tissue. The pia mater is bilaterally thickened along the lateral surface of the spinal cord, forming the denticulate ligament (Fig. 14-39 and 63). Extensions of the denticulate ligament traverse the subarachnoid space and attach to the dura mater, thus suspending the spinal cord in cerebrospinal fluid within the subarachnoid space. Cranial vessels are surrounded by the pia mater for a short distance after entering the brain. Cerebrospinal fluid is thought to be able to enter the veins at these pial sleeves.

Ventricles and cerebrospinal fluid

The lumen of the embryonic neural tube persists as the ventricles of the brain and the central canal of the spinal cord. These cavities are lined by **ependymal epithelium** and are filled with **cerebrospinal fluid.**

The ventricular system of the brain consists of **two lateral ventricles,** one in each hemisphere, the **third** and the **fourth ventricle** (Fig. 14-42 and 43). Each lateral ventricle communicates with the third ventricle through an **interventricular foramen.** The third ventricle is a narrow, midsagittal chamber that surrounds the interthalamic adhesion of the diencephalon. The **mesencephalic aqueduct** of the midbrain is a canal that joins the third to the fourth ventricle. The fourth ventricle is located in the **rhombencephalon** and is continuous with the **central canal of the spinal cord.** Cerebrospinal fluid is normally a clear, colourless liquid formed from the blood plasma by the **choroid plexus** of the brain. The choroid plexus consist of an epithelium and the underlying pia mater. They are adherent to the walls of the ventricle by an attachment of the pia mater. The attachment line is termed the taenia choroidea.

One choroid plexus is located in **each lateral ventricle** and two choroid plexus are present in the **third** and the **fourth ventricle.** Cerebrospinal fluid flows within the ventricular system and into the central canal. It flows into the subarachnoid space from the fourth ventricle through bilateral recesses and apertures. In humans and carnivores a third, median aperture is present. Two major drainage roots for the return of cerebrospinal fluid to the blood are arachnoid villi and the lymphatics associated with peripheral nerves.

The cerebrospinal fluid cushions the central nervous system and acts as a chemical buffer. It also transports nutrients and waste products, thereby taking over the function of the lymphatics lacking in the brain.

Blood vessels of the central nervous system

Blood vessels of the spinal cord

The cervical spinal cord is vascularised by segmental arteries from the **vertebral artery,** a branch of the **subclavian artery.** The remainder of the spinal cord receives its blood supply from **segmental arteries** from the cervical, intercostal and lumbar arteries. The segmental arteries enter the vertebral canal through the intervertebral foramina. There, each divides into a dorsal and a ventral branch, which reach the spinal cord together with the spinal nerves.

The branches unite to form three continuous arteries that run along the length of the spinal cord: the **ventral spinal artery** and the **paired dorsolateral spinal arteries.** The ventral

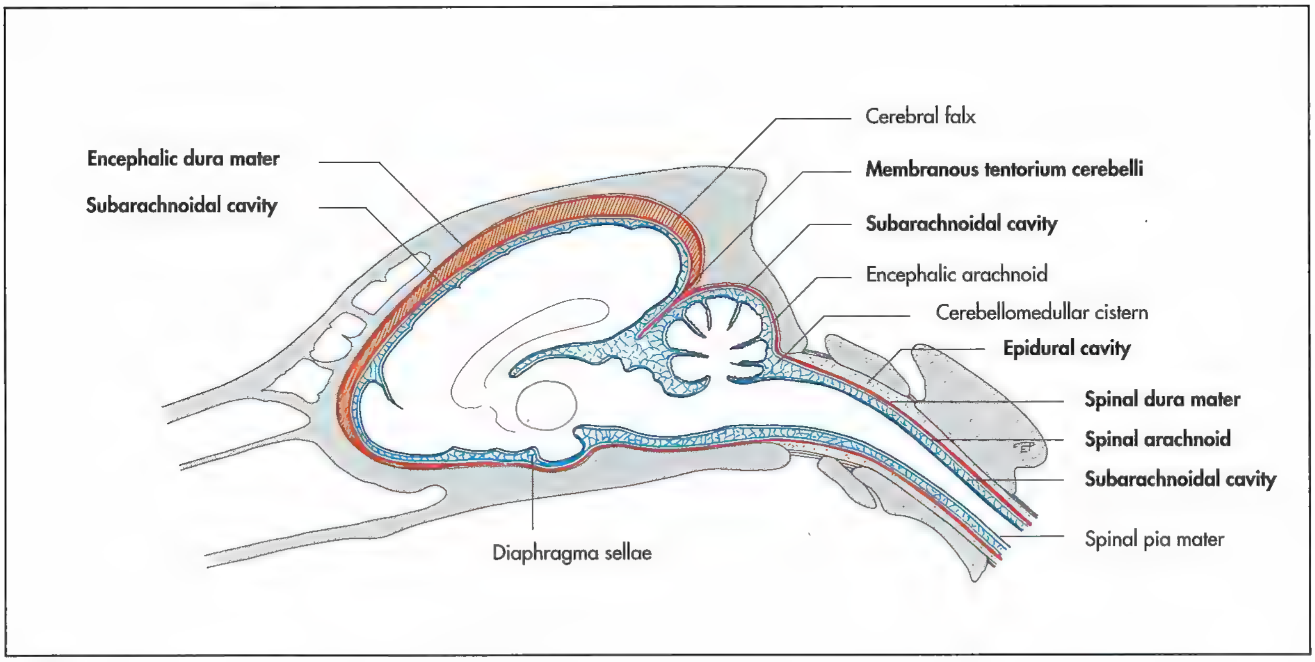


Fig. 14-38. Meninges of the cranium and the cranial part of the cervical spine of the dog, schematic (red = pachymeninx, blue = leptomeninx).

spinal artery is the largest of the three and lies at the ventral median fissure. The smaller dorsolateral arteries extend along the lateral dorsal sulci, where the dorsal roots emerge (Fig. 14-39 and 44). These arteries form plexuses at the surface of the spinal cord, from which deeper parts of the cord are supplied. The grey matter receives a far more generous blood supply than the white matter (Fig. 14-8).

The **spinal veins** form a **network** similar to the arterial plexus. The draining veins also follow the spinal nerves before they open into the **epidural venous plexus.** The epidural venous plexus consists of two channels within the epidural space on the ventral aspect of the spinal cord that are composed of segments extending between successive intervertebral foramina. The two channels are regularly connected by transverse

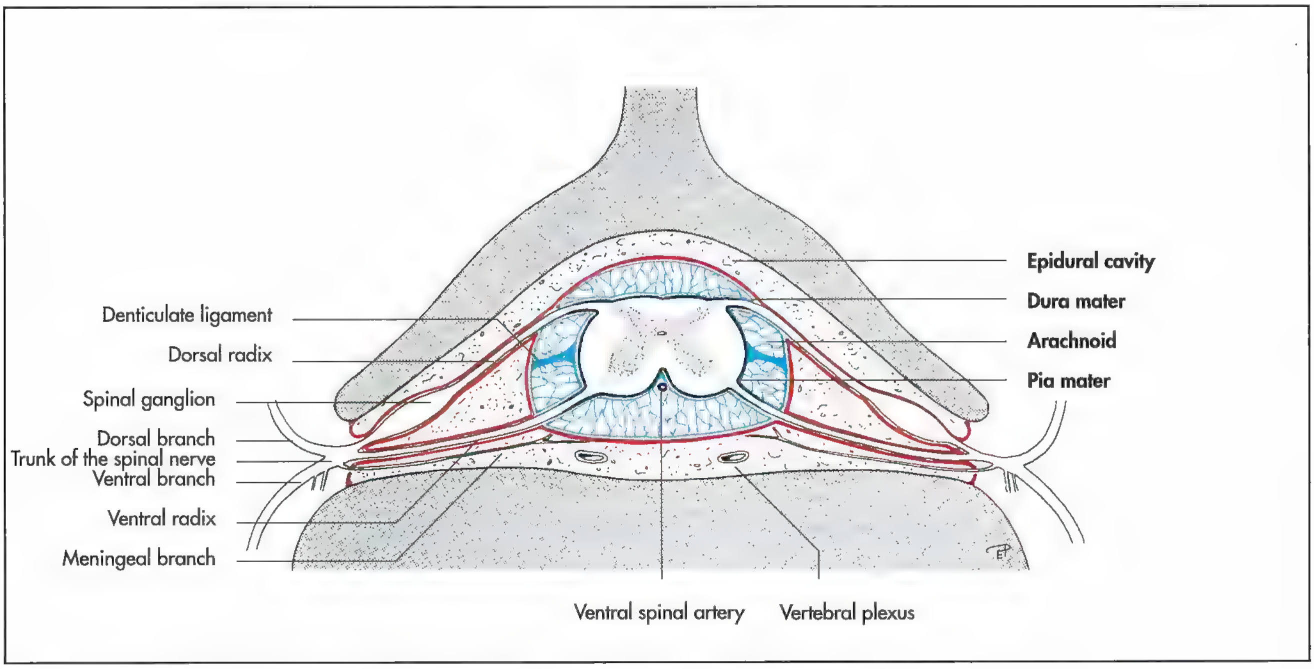


Fig. 14-39. Spinal meninges of the dog, schematic (red = pachymeninx, blue = leptomeninx).

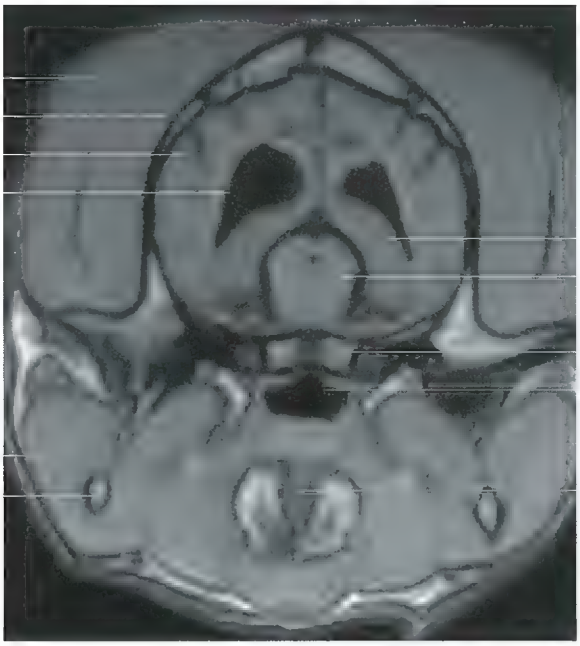


Fig. 14-40. Magnetic resonance image of the head of a dog, transverse section rostral to the tempormandibular joint, caudal aspect (courtesy of Dr. Sibylle Kneissl, Vienna).

branches, producing a ladder-like pattern of vessels. The veins composing the plexus are thin-walled and have **no valves,** so that blood can **pass in either direction.** The epidural venous plexus are connected with venous plexus outside the vertebral column, which drain into the vertebral vein, the cranial vena cava, the azygous vein or the caudal vena cava.

Since the epidural venous system provides alternative channels to the major systemic veins it may serve as an alternative route, when obstruction of either the jugular vein or the caudal vena cava occurs. However, blood flow is comparatively slow or sometimes even stops in the epidural veins. The slow venous flow facilitates spread of septic or neoplastic

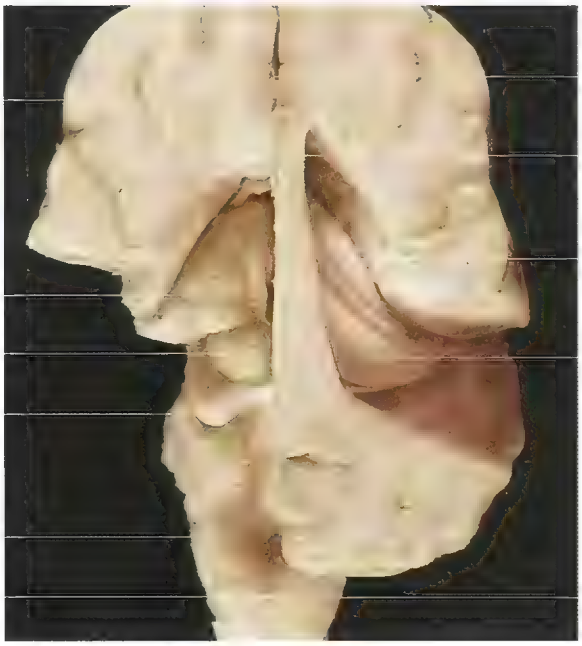


Fig. 14-41. Cerebral ventricles of a dog, dorsal aspect (courtesy of Prof. Dr. W. Künzel, Vienna).

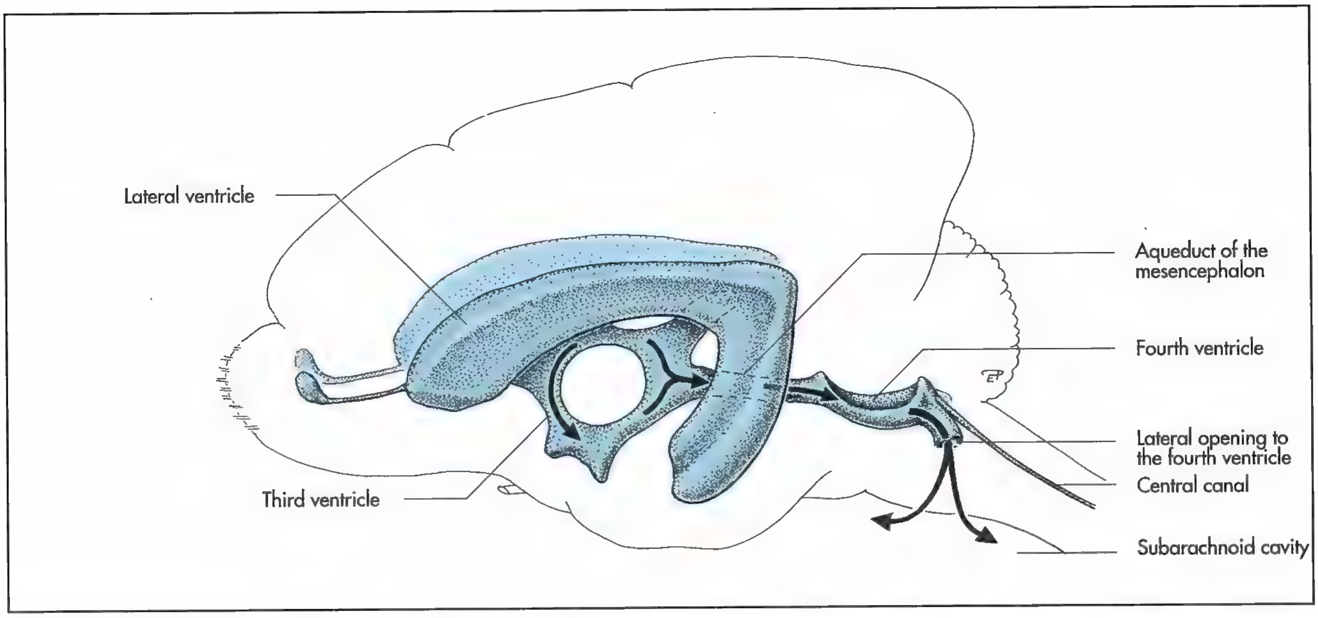


Fig. 14-42. Cerebral ventricles of the dog, demonstrating the flow of the cerebrospinal fluid (arrows), lateral aspect (Anderson and Anderson, 1994).

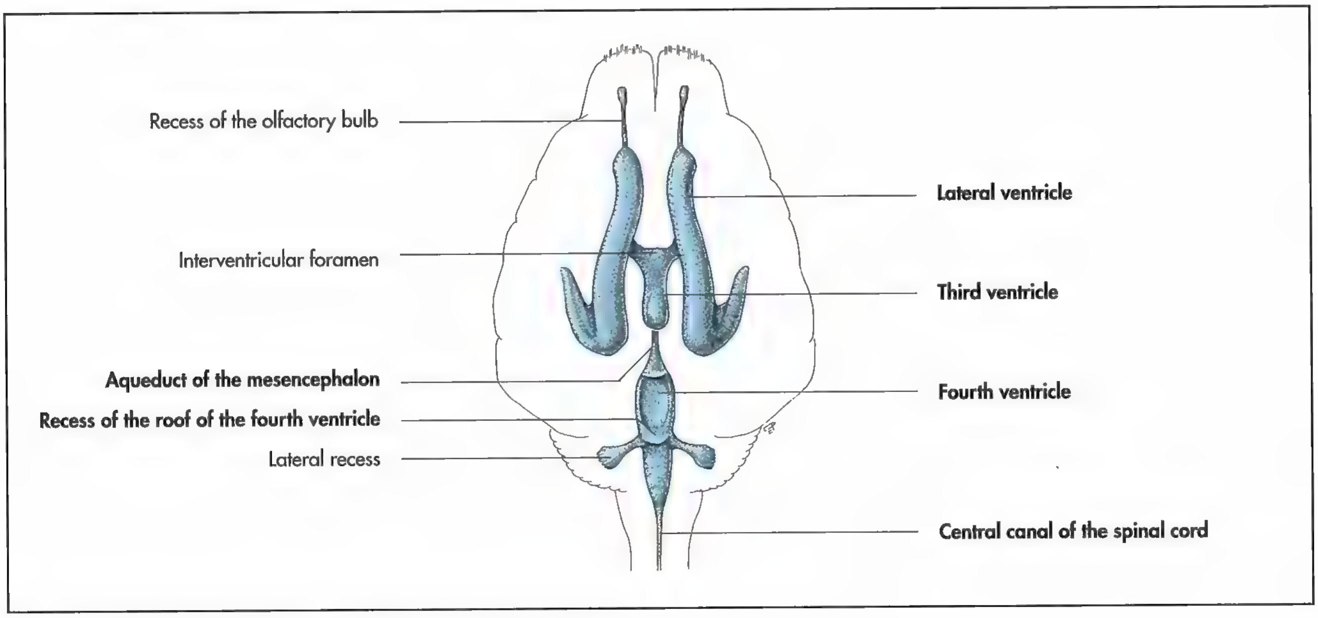


Fig. 14-43. Cerebral ventricles of the dog, dorsal aspect (Anderson and Anderson, 1994).

diseases, allowing tumour cells or micro-organisms to invade this area.

Another point of clinical importance is the risk of haemorrhage from the epidural venous plexus during epidural puncture or surgery (e.g. laminectomy).

Blood vessels of the brain

In the horse and dog, the blood supply to the brain comes mainly from the **paired internal carotid arteries.** In the cat and in ruminants in which the internal carotid closes shortly after birth, the main blood supply to the brain is provided by branches of the maxillary artery. These branches form a complicated **arterial network** at the base of the brain, which con-

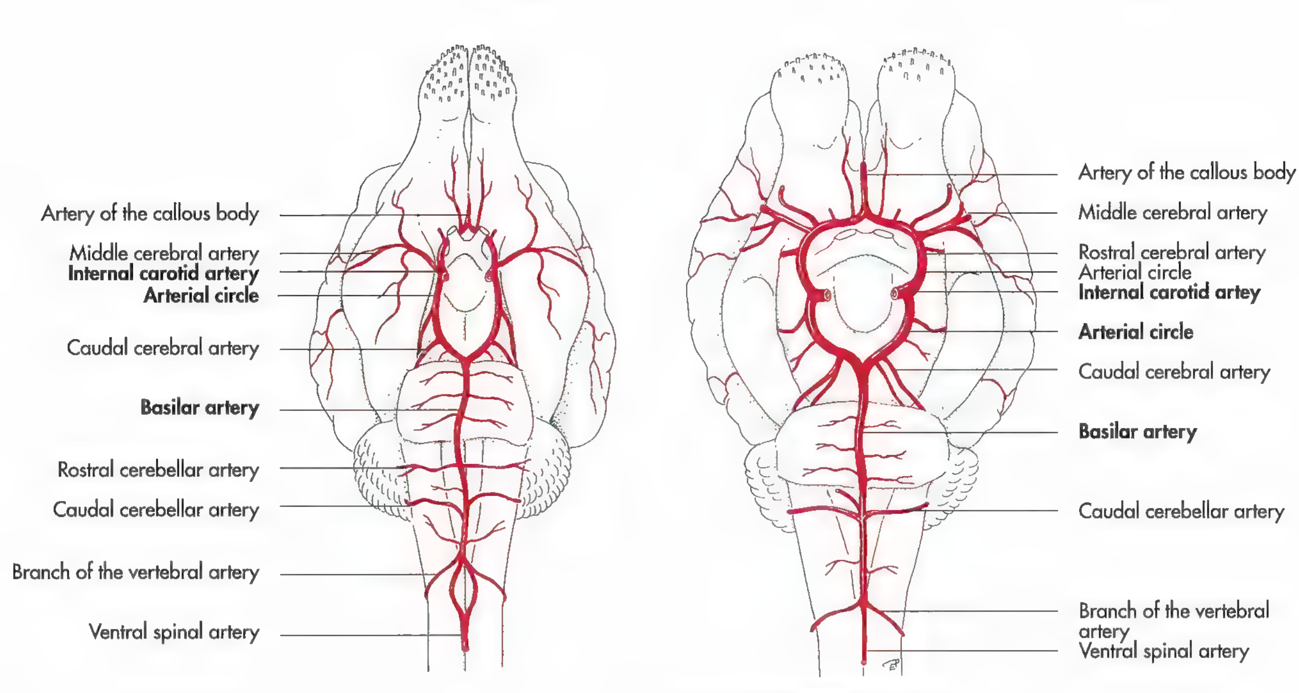


Fig. 14-44. Basal arteries of the brain of the dog, left (Budras, 1996) and the horse, right (Rösslein, 1987), ventral aspect.

sists of the rostral and caudal **epidural rete mirabile,** which reunite in the **cerebral carotid artery.** The internal carotid artery of the pig also forms a rostral rete mirabile.

The **internal carotid artery** in the horse and dog and the cerebral carotid artery in the other domestic mammals penetrates the dura mater at the **diaphragma sellae** and forms a **ring** around the infundibular stalk ventral to the hypothalamus. This **cerebral arterial circle** (circulus arteriosus cerebri), formerly known as the **Circle of Willis,** is only complete in the dog, while it remains open rostrally in the other domestic mammals (Fig. 14-44 and 45). The arterial circle is joined caudally by the **basilar** and the **vertebral arteries.** In the ox, the vertebral artery contributes a considerable proportion to the circle of Willis. The arterial cerebral circle and the basilar artery give rise to all other cerebral arteries (Fig. 14-44 to 50).

The main branches are the:

- Rostral cerebral artery (a. cerebris rostralis),
- Middle cerebral artery (a. cerebri media),
- Caudal cerebral artery (a. cerebri caudalis),
- Rostral cerebellar artery (a. cerebelli rostralis) and
- Caudal cerebellar artery (a. cerebelli caudalis).

The **main cerebral arteries** are located on the surface of the brain from which they extend small arteries and arterioles into the neural tissue, which then branch into smaller vessels. While the **grey matter** contains a very dense network of capillaries, the **white matter** receives a less generous blood supply (Fig. 14-47 and 48).

The permeability of the blood capillaries within the neural tissue is reduced by the so-called **blood-brain barrier,** which is formed by the endothelium of the capillaries and the surrounding glial cells.

Intracerebral anastomoses are rare and, when present, so narrow, that they connect functional end-arteries. Occlusion of one of these end arteries e.g. by blood clots, air or fat emboli results in the death of the neural tissue it supplies. In human beings, the middle cerebral artery and its branches seem to be predisposed.

The **veins of the brain** can be grouped in **dorsal, basal** and **inner veins,** that are **valve-less** and run independently from the arteries before they open into the also valve-less **dural venous sinuses** (sinus durae matris) (Fig. 14-47 and 48). The sinuses enclosed within the dura mater are divided in dorsal and ventral systems.

The **dorsal system** includes the **dorsal sagittal sinus,** which collects the blood from the dorsal parts of the brain and the bones of the cranial vault. It passes within the falx cerebri and is joined towards its caudal end by the straight sinus before dividing into the transverse sinuses, which extend to both sides in the membranous tentorium cerebelli.

The **transverse sinuses** receive the blood from the cerebellar veins. The transverse sinuses unite with the **temporal sinus,** which opens in the retroarticular foramen and connects with the **ventral system** (except in the horse). The straight sinus is continuous with the great cerebral vein, which drains the inner parts of the brain.

The **ventral or basilar system** drains the ventral part of the brain and parts of the face. It consists of the cavernous sinus, which **surrounds the hypophysis** and is closely related to the distal sigmoid end of the internal carotid artery or the **epidural rete mirabile** respectively. The ventral system re-

Fig. 14-45. Arteries at the base of the brain of a horse, corrosion cast (Rösslein, 1987).

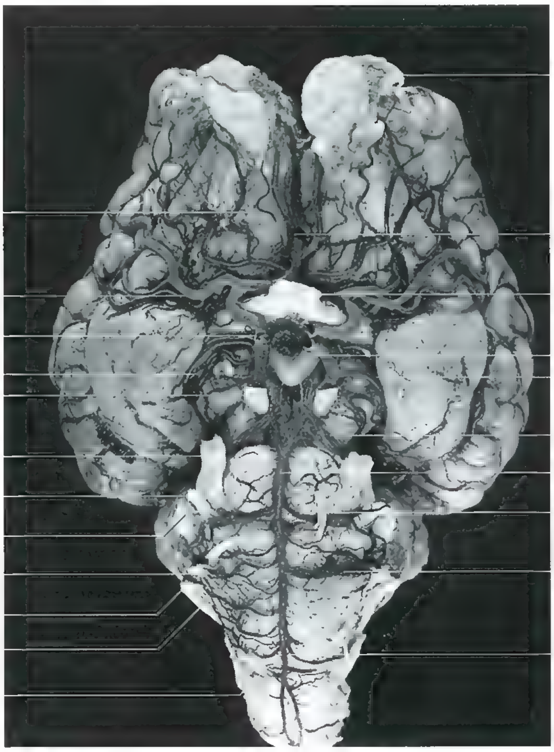


Fig. 14-46. Arteries at the base of the brain of an ox (König, 1979).

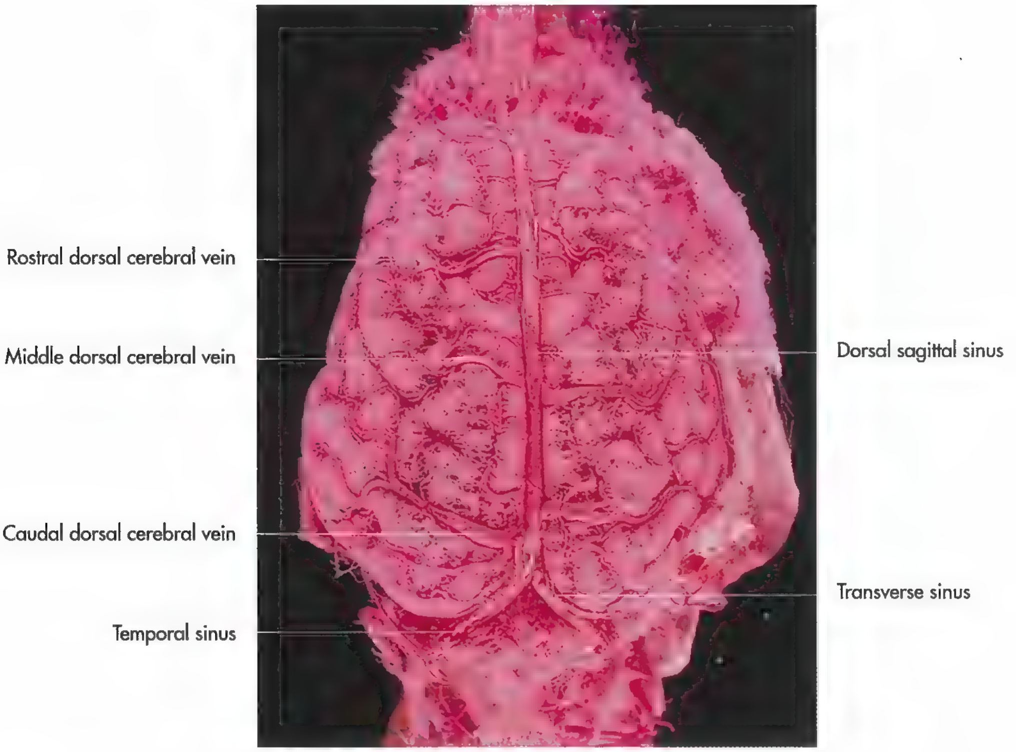


Fig. 14-47. Dorsal bloodvessels of the brain of a young pig, corrosion cast.

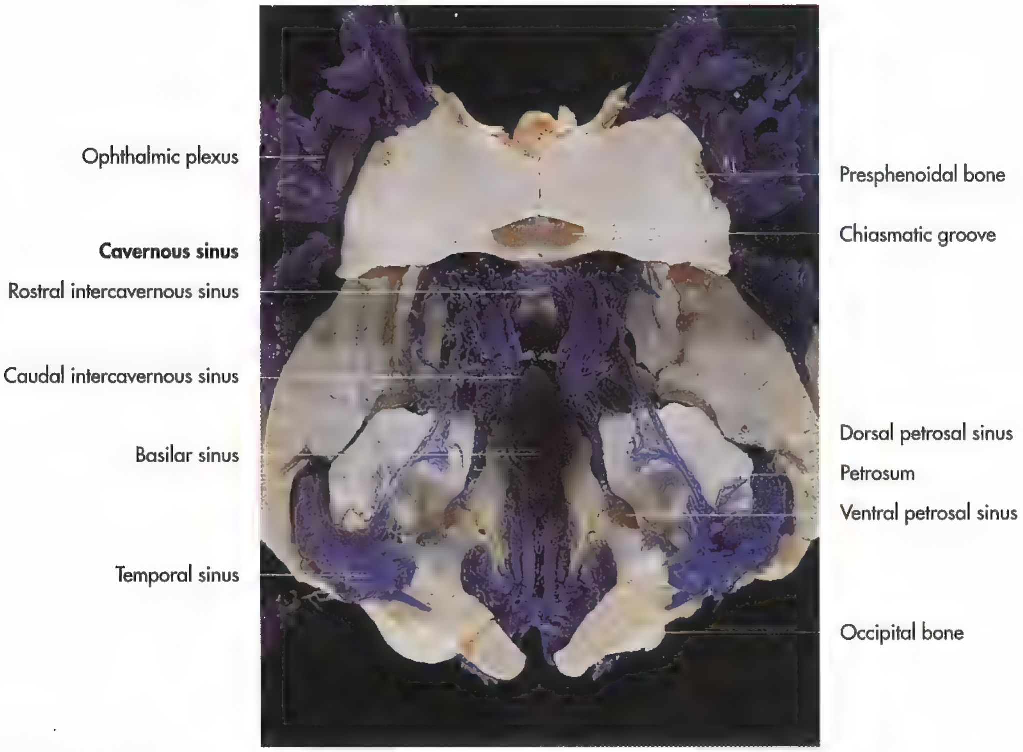


Fig. 14-48. Basal sinus system of the brain of an ox, corrosion cast (König, 1979).

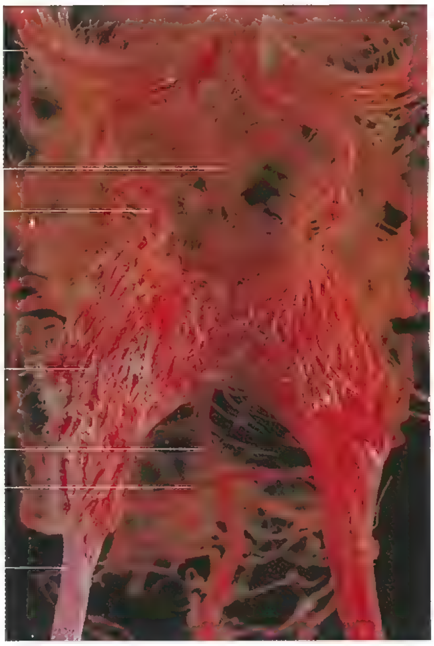


Fig. 14-49. Arteries of the cranial base of a pig, corrosion cast (Engelkraut, 1987).

Fig. 14-50. Microvascularisation of the cerebral cortex (König, 1979).

ceives considerable contribution from the face, orbit and nasal cavity by the deep facial vein. This arrangement cools the arterial blood supply to the brain, since the internal carotid artery is bathed in the colder venous blood, when it passes through the cavernous sinus.

Peripheral nervous system (systema nervosum periphericum)

The nerves and ganglia of the peripheral nervous system do not form an independent functional unit, but are all connected to the central nervous system.Based on morphology and function they can be grouped in two different systems:

The **cerebrospinal (oikotrop) nerves** and **ganglia** connect the central nervous system with the **sensory organs** and the **skeletal musculature.** The cerebrospinal system is responsible for the stimulus-response interaction between the environment and the organism.

The **autonomous (idiotrop) nerves** and **ganglia** connect the central nervous system with the **viscera** and components of the **circulatory system.** This system is responsible for the regulation and co-ordination of the inner organs. Depending on the function, it can be further subdivided into a sympathetic and parasympathetic division.

Cerebrospinal nerves and ganglia

The cerebrospinal nerves are divided into:

- Cranial nerves (nn. craniales),
- Spinal nerves (nn. spinales).

The cell bodies of the **cerebrospinal nerves** are either located in nuclei within the central nervous system or in ganglia close to the central nervous system. Their axons connect the effector organ directly to the central nervous system without forming synapses.

Spinal nerves are of the mixed type, consisting of both, sensory and motor fibres, which are joined in most cases by autonomous fibres as well (Fig. 14-51 and 52). Cranial nerves can be classified as sensory, motor or mixed. Some of them have autonomous fibres, which often show an unusual pattern with regards to their course.

Cranial nerves (Nn. craniales)

Classic anatomy describes 12 paired cranial nerves, although the first two are not peripheral nerves:

- Olfactory nerve (I) (n. olfactorius),
- Optic nerve (II) (fasciculus opticus),
- Oculomotor nerve (III) (n. oculomotorius),
- Trochlear nerve (IV) (n. trochlearis),
- Trigeminal nerve (V) (n. trigeminus),
- Abducent nerve (VI) (n. abducens),
- Facial nerve (VII) (n. facialis),
- Vestibulocochlear nerve (VIII) (n. vestibulocochlearis),
- Glossopharyngeal nerve (IX) (n. glossopharyngeus),
- Vagus nerve (X) (n. vagus),
- Accessory nerve (XI) (n. accessorius) and
- Hypoglossal nerve (XII) (n. hypoglossus).

Based on function and embryonic development the cranial nerves can be arranged in groups:

- the **sensory group** comprises the nerves that are only concerned with sensory organs; these are the olfactory, optic and vestibulocochlear nerves,

Fig. 14-51. Histological section of a mixed nerve.

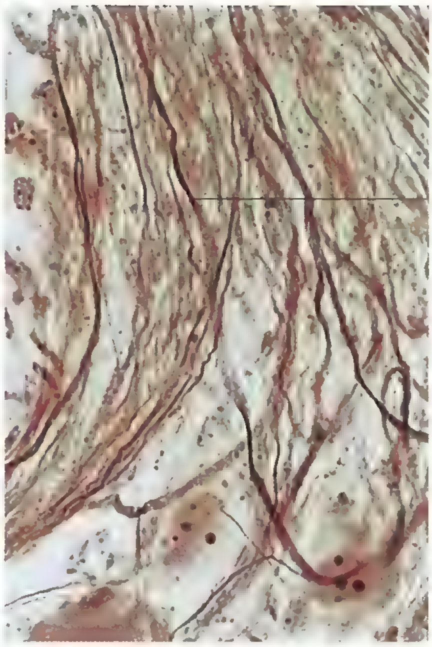


Fig. 14-52. Histological section of a bundle of autonomous nerve fibres.

- the second group includes the nerves that innervate the **ocular muscles,** this group comprises the oculomotor, trochlear and abducent nerves,
- the third group comprises the so-called **branchial nerves** that innervate structures that take their embryological origin from the branchial arches; these are the trigeminal, facial, glossopharyngeal, vagal and accessory nerves,
- based on its embryological development the hypoglossal nerve can be classified as the remnant of a **cervical spinal nerve.**

The **cranial nerves** have certain characteristic feature that distinguishes them from the spinal nerves: They do not have a segmental embryonic precursor, their root is not divided into afferent and efferent tracts, but have a single combined outflow. Unlike spinal nerves, which have both sensory and motor functions, cranial nerves can be solely motor, solely sensory or mixed. Cranial nerves I, II and VIII are sensory, III, IV, VI, XI and XII are motor, while V, VII, IX and X are sensory and motor.

Olfactory nerve (I)

The olfactory nerve is not a single nerve, but consists of numerous **nonmyelinated axons,** whose cell bodies are located within the **olfactory epithelium.** These axons pass through the cribriform plate of the ethmoid to reach the olfactory bulbs, where they synapse. The **terminal nerve** (n. terminalis) from the vomeronasal organ is combined within the olfactory nerve. This relatively thin nerve ends in the rostral part of the **rhinencephalon** (Fig. 14-25 and Table 14-1). Some authors describe this nerve separately as cranial nerve.

Optic nerve (II) (fasciculus opticus)

The optic nerve is not a true peripheral nerve, but a tract of the brain. The fibres of the optic nerve originate from the **retina,** which develops from the **diencephalon.** The optic nerve is also enclosed by extensions of the **meninges,** the dura, which blend with the sclera where the nerve leaves the globe. The axons of the optic nerve accumulate at the **optic disc of the retina.** The optic nerve leaves the eyeball on its caudal aspect and enters the cranial cavity by passing through the **optic canal** (Fig. 14-29, 53 and Table 14-1).

After nerve fibres decussate to the opposite side at the **optic chiasm,** they form the optic tracts at the base of the brain. The optic fibres terminate in the **lateral geniculate nucleus,** the rostral colliculi of the **quadrigeminal plate** and the **thalamic nuclei,** where they synapse with fibres, which project onto the **visual cerebral cortex** in the **occipital lobe.**

Oculomotor nerve (III)

The oculomotor nerve consists of **somatic efferent fibres** from the **motor nucleus** and **visceral efferent neurons** from the **parasympathetic nucleus.** Both nuclei are located within the **tegmentum** of the midbrain. The motor nucleus is the principal nuclei of this nerve.

The **oculomotor nerve** exits the brain stem on the ventral aspect of the **cerebral peduncles.** It passes rostrally, sharing a common dural sheath with the ophthalmic and abducent nerve, before it leaves the cranial cavity through the **round foramen** (foramen rotundum) or through the combined **orbital fissure** and **round foramen** (foramen orbitorotundum) respectively. On entering the orbit, the oculomotor nerve divides into a dorsal and a ventral branch.

The **dorsal branch** innervates the levator palpebrae muscle and ends in the dorsal rectus muscle. The **ventral branch** terminates in a number of branches, which innervate the medial rectus, the ventral rectus and the ventral oblique muscles. The parasympathetic fibres travel within the ventral branch and synapse with postganglionic neurons in the **cil-**

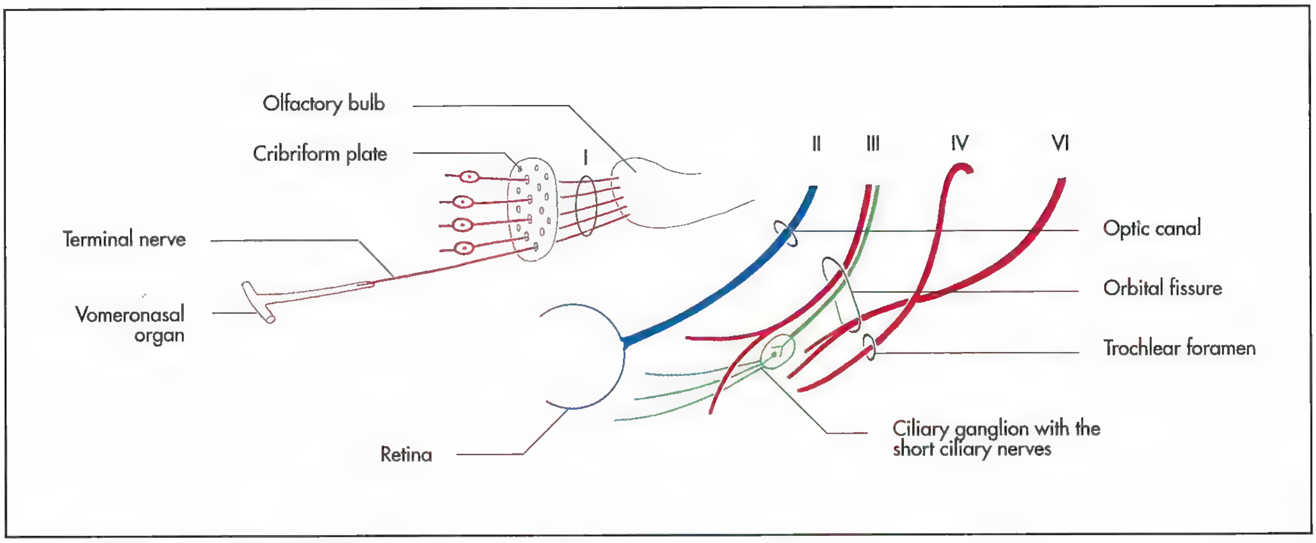


Fig. 14-53. Schematic illustration of the olfactory (light red), optic (blue), oculomotor, trochlear and abducent (red) nerves, parasympathetic fibres (green) (Budras and Röck, 1997).

iary ganglion, located at the origin of the branch for the ventral oblique muscle. The postganglionic fibres innervate the ciliary muscle and the sphincter pupillary muscle, responsible for constriction of the pupil.

The oculomotor nerve includes some **sensory fibres,** which join the ophthalmic branch of the trigeminal nerve and extends to the **trigeminal ganglion.**

Trochlear nerve (IV)

The trochlear nerve consists of **motor fibres,** that arise from the **trochlear nuclei** in the tegmentum of the midbrain and innervates the dorsal oblique muscle of the eye. It is the only nerve that emerges from the dorsal aspect of the brain stem after crossing to the contralateral side at the trochlear decussation (decussation nervorum trochlearium) (Fig. 14-53 and Table 14-1).

The **trochlear nerve** penetrates the dura mater at the ventral fold of the tentorium cerebelli and passes rostrally, lateral to the maxillary nerve. It leaves the cranial cavity through the round foramen, except in the horse, where a separate opening (foramen trochleare). The oculomotor nerve comprises few **sensory fibres.**

Trigeminal nerve (V)

The trigeminal nerve is a complex nerve of the mixed type. It is the **largest sensory nerve of the head.** It is composed of sensory fibres from the skin and deeper tissues of the head and **motor fibres** to the masticatory musculature, the mylohyoid muscle, the rostral portion of the digastric muscle, the tensor muscle of the soft plate and the tensor tympani muscle (Fig. 14-46, 54 to 57 and Table 14-1).

The **motor nucleus of the trigeminal nerve** (nucleus motorius n. trigemini) is found in the **metencephalon,** deep to the locus caeruleus of the rhomboid fossa. The **sensory fibres** arise from the pseudounipolar neurons of the **trigeminal ganglion** and pass to the sensory trigeminal nuclei in the mesencephalon, pons and spine.

The **nuclei of the mesencephalic tracts** (tractus mesencephali) of the trigeminal nerve consist of pseudounipolar neurons, whose fibres pass through the trigeminal ganglion without synapsing. Thus, this nucleus takes over the role of a sensory ganglion within the brain.

The **trigeminal nerve** emerges on the lateral aspect of the (radix motoria). The **trigeminal ganglion** is located in a dural fold within the petrosal bone. As the nerve leaves the trigeminal ganglion, it divides into three main branches:

- Ophthalmic nerve (n. ophthalmicus, V_1),
- Maxillary nerve (n. maxillaris, V_2),
- Mandibular nerve (n. mandibularis, V_3).

Ophthalmic nerve (V_1)

The ophthalmic nerve passes rostrally, lateral to the hypophysis within a common dural sheath with the maxillary, trochlear and abducent nerve. The nerves leave the cranial cavity and enter the orbit through the round foramen or the orbital fissure, respectively (Fig. 14-54 and Table 14-1). It is closely related to the cavernous sinus and in ruminants, pigs and cats, to the **epidural rete mirabile.** After entering the orbit the ophthalmic nerve divides into the:

- Lacrimal nerve (n. lacrimalis),
- Frontal nerve (n. frontalis),
- Nasociliary nerve (n. nasociliaris),
  - Ethmoidal nerve (n. ethmoidalis) and
  - Infratrochlear nerve (n. infratrochlearis).

Covered by the periorbita, the **lacrimal nerve** runs along the lateral straight muscle of the eyeball to supply the lacrimal gland, the skin and conjunctiva of the temporal canthus of the eye. In the ox it contributes the majority of the fibres (together

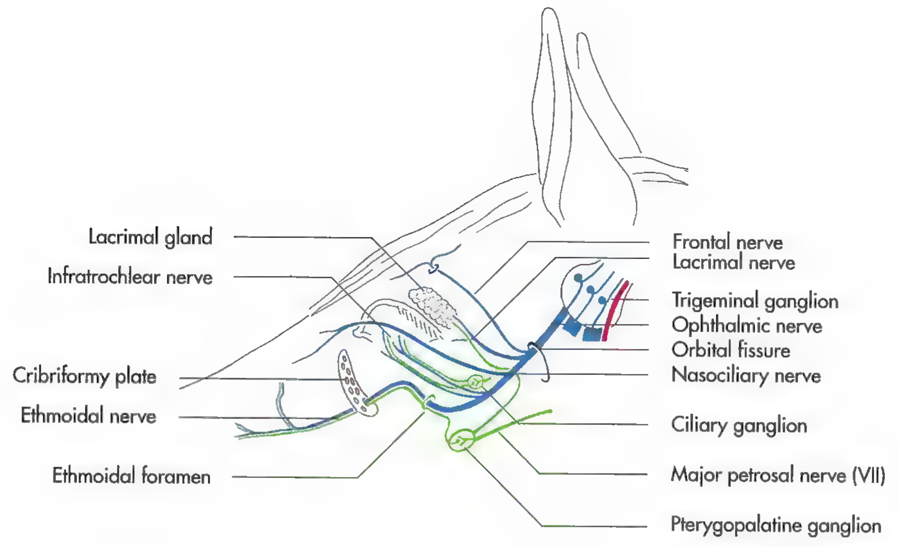


Fig. 14-54. Schematic illustration of the primary branches of the ophthalmic nerve in the horse (blue = sensory, red = motor, green = parasympathetic fibres).

with the zygomatic nerve) to the cornual branch. The **secretory fibres** for the innervation of the lacrimal gland come from the intermedial portion of the intermediofacial nerve and form synapses in the **pterygopalatine ganglion.** The postganglionic fibres run with the maxillary and zygomatic nerve before they join the lacrimal nerve.

The **frontal nerve** passes rostrally under the periorbita dorsal to the dorsal oblique and dorsal rectus muscles of the eyeball. Upon reaching the dorsal margin of the orbit, it penetrates the periorbita and winds around its dorsal margin. In the horse, it passes through the supraorbital foramen. It innervates the skin and conjunctiva of the upper lid, the nasal canthus and the forehead. One branch extends to the frontal sinus.

The **nasociliary nerve** is the largest branch of the ophthalmic nerve. It passes lateral to the optic nerve before crossing over it to reach the medial aspect of the orbit. The nasociliary nerve gives off the short and long ciliary nerves before it bifurcates into the ethmoidal and the infrachtrochlear nerves. The short ciliary nerves pass through the ciliary ganglion. The ciliary nerves run between the sclera and choroid to reach the iris. They extend branches into the bulbar conjunctiva, the ciliary muscle and the cornea.

The **ethmoidal nerve** passes through the ethmoidal foramen to re-enter the cranial cavity. Staying external to the dura mater, it runs to the cribriform plate through which it enters the nasal cavity. It innervates the olfactory mucosa with sensory fibres and sends branches to the frontal sinus and the roof of the nasal cavity to the nasal apex.

The **infratrochlear nerve** runs along the medial aspect of the orbit to the nasal canthus, where it innervates the conjunctiva, the third eyelid and the lacrimal caruncles.

Maxillary nerve (V_2)

The maxillary nerve is considerably stronger than the ophthalmic nerve. It is **sensory** to the lower eyelid, nasal mucosa, upper teeth, upper lip, and nose. Its distal branches comprise of **postganglionic fibres** that supply the lacrimal, nasal and palatine glands. Before leaving the cranial cavity through the **round foramen and orbital fissure** respectively, it detaches the **meningeal branch** (ramus meningeus) for the basal parts of the dura mater (Fig. 14-55 and 14-1). In the pterygopalatine fossa it divides into the:

- Zygomatic nerve (n. zygomaticus),
- Pterygopalatine nerve (n. pterygopalatinus),
- Infraorbital nerve (n. infraorbitalis).

Closely related to the maxillary nerve is the **parasympathetic pterygopalatine ganglion,** which is located medial to the nerve in its course through the pterygopalatine fossa. The **zygomatic nerve** runs on the lateral aspect of the orbit. It innervates the skin of the temporal and frontal region, together with the lacrimal, frontal and auriculopalpebral nerves. It contributes to the cornual nerve, which innervates the horn in ruminants. It provides the lacrimal nerve with parasympathetic fibres from the **pterygopalatine ganglion.** The zygomatic nerve is not present in the cat. The **pterygopalatine nerve** arises from the deep surface of the maxillary nerve from where it passes rostrally. It divides into the:

- Caudal nasal nerve (n. nasalis caudalis),
- Major palatine nerve (n. palatinus major),
- Minor palatine nerve (n. palatinus minor).

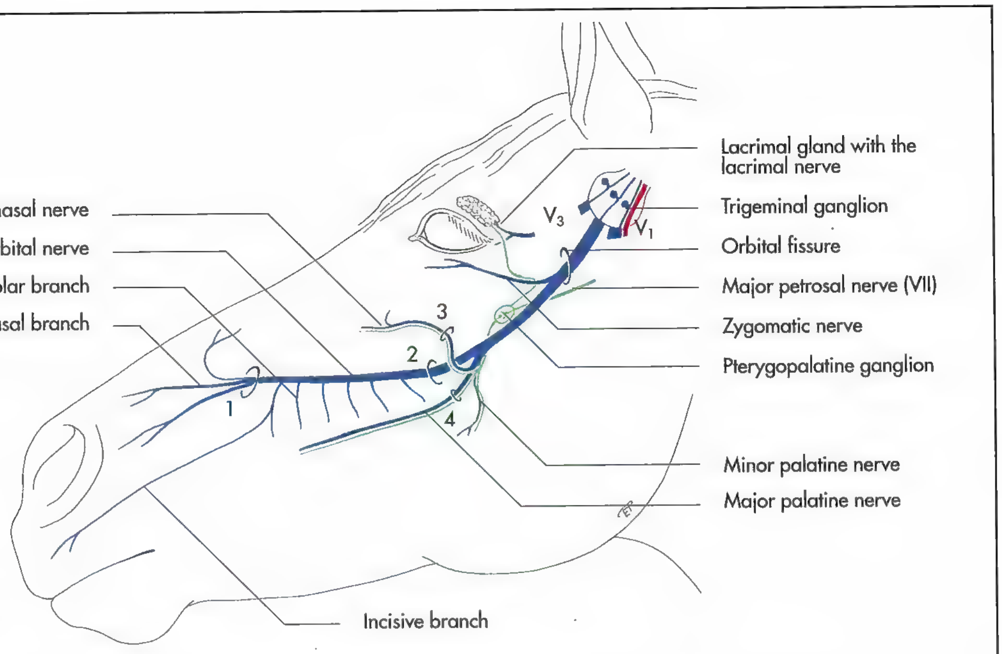


Fig. 14-55. Schematic illustration of the primary branches of the maxillary nerve in the horse (blue = sensory, red = motor, green = parasympathetic fibres).

The **caudal nasal nerve** leaves the pterygopalatine fossa through the sphenopalatine foramen to enter the nasal cavity. It divides into a medial and lateral branch that provides sensory innervation to the nasal septum and to the nasal mucosa of the ventral nasal conchae and the ventral and middle meatus.

The **major palatine nerve** enters the palatine canal through the major palatine foramen and innervates the mucosa of the hard palate. The thin, **minor palatine nerve** provides sensory innervation to the soft palate. The infraorbital nerve is the direct continuation of the maxillary nerve. It enters the infraorbital canal at the maxillary foramen and reappears rostrally on the face through the infraorbital foramen. It gives off **alveolar branches** (rami alveolares) to the maxillary cheek teeth and innervates the skin on the nose, the skin and mucosa of the muzzle and the upper lip. **Branches of the maxillary nerve** convey secretory-parasympathetic fibres from the pterygopalatine ganglion to the lacrimal gland and to various glands of the nose and palate.

Mandibular nerve (V_3)

The mandibular nerve is as strong as the maxillary nerve, but in contrast to the other branches of the trigeminal nerve it is both, **sensory** and **motor** (Fig. 14-56 and Table 14-1). It provides motor innervation to the muscles concerned with prehension and mastication. It provides sensory innervation to the buccal cavity, tongue, mandibular teeth, the lower lip and parts of the facial skin. After detaching a meningeal branch, the mandibular nerve leaves the cranial cavity via the oval foramen (oval incisura in the horse). It detaches the following primary branches:

- Masticator nerve (n. masticatorius)
- Buccal nerve (n. buccalis)
- Auriculotemporal nerve (n. auriculotemporalis) formerly termed superficial temporal nerve (n. temporalis superficialis),
- Lingual nerve (n. lingualis) and
- Inferior alveolar nerve (n. alveolaris inferior).

Just after its passage through the oval foramen, the mandibular nerve detaches the masticator nerve, that divides into the **masseteric nerve** (n. massetericus) and the **deep temporal nerves** (nn. temporales profundi). The masseteric nerve passes through the mandibular notch between the condylar and the coronoid process of the mandible to enter the masseter muscle on its lateral side. The deep temporal nerves are motor to the temporal muscle.

The **medial** and **lateral pterygoid nerve** arise from the mandibular nerve ventromedially and innervate the like-named masticatory nerve. Close to the origins of masticatory nerves lies the otic ganglion. Motor nerves for the tensor muscle of the soft plate and tensor tympani muscle leave the mandibular nerve at the level of the otic ganglion.

The **buccal nerve** passes rostrally between the lateral pterygoid muscle and the temporal muscle to reach the cheeks. It is sensory to the mucosa and the skin of the cheek and conveys secretory fibres from the otic ganglion to the buccal glands. (The term buccal branches (rami buccales) designate the motor branches of the intermediofacial nerves to the cheeks).

The **auriculotemporal nerve** arises from the caudal border of the mandibular nerve. It is covered by the parotid salivary gland and bends around the caudal border of the

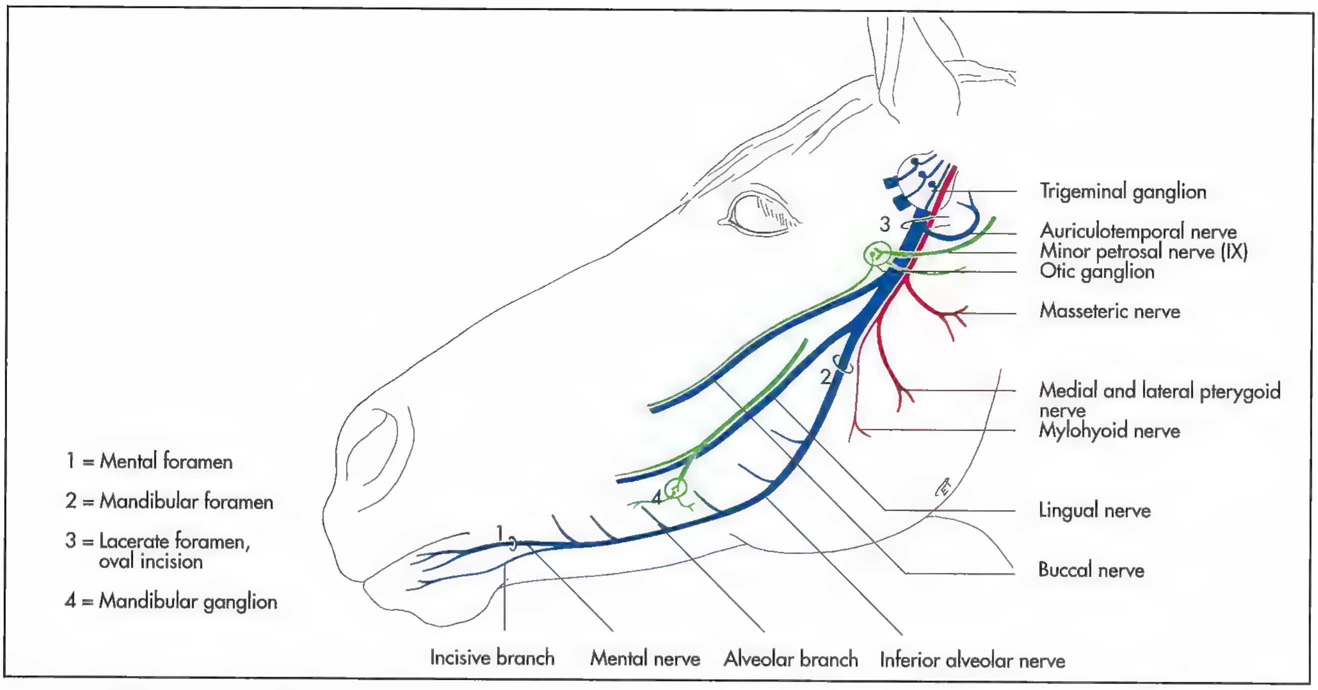


Fig. 14-56. Schematic illustration of the primary branches of the mandibular nerve in the horse without the deep temporal nerves (blue = sensory, red = motor, green = parasympathetic fibres).

mandible to reach the face just ventral to the temporomandibular joint. It divides into an auricular branch and a temporal branch. The auricular branch runs along the rostral margin of the external acoustic meatus to the base of the external ear, and innervates the skin in this area, together with the rostral auricular branch of the intermediofacial nerve. The temporal branch detaches smaller nerves, which innervate the external acoustic meatus, the parotid gland and the skin of the cheeks.

The **mandibular nerve** terminates by bifurcating into the lingual and the inferior alveolar nerves. The inferior alveolar nerve passes between the lateral and medial pterygoid muscles. Before entering the mandibular canal at the mandibular foramen, it detaches its last motor branch, the mylohyoid nerve, which innervates the mylohyoideus muscle and the rostral belly of the digastric muscle. It passes through the mandibular canal supplying alveolar sensory nerves to the teeth and reappears at the mental foramen as the mental nerve, which innervates the skin and mucosa of the lower lip and chin.

The **lingual nerve** passes lateral to the stylohyoid, then medial along the mylohyoideus to reach the tongue, where it divides into **deep and superficial branches.** It is sensory to the mucosa of the rostral two thirds of the tongue and the floor of the oral cavity. It is joined by the chorda tympani, a branch of the intermediofacial nerve, which introduces sensory and parasympathetic fibres from the mandibular ganglion. These supply secretory innervation to the sublingual and mandibular glands.

Damage to the trigeminal nerve causes paralysis of the masticatory muscles characterised by a dropped jaw. This condition is most common in the dogs, in which it may be an idiopathic condition. In many cases it occurs, concurrently with paralysis of the hypoglossal nerve, which causes the tongue to hang out of the mouth in affected animals. Most common aetiologies include brain abscesses, brain trauma and rabies.

Abducent nerve (VI)

The abducent nerve provides motor innervation to the lateral rectus bulbi muscle and the lateral quarter of the retractor bulbi muscle of the eyeball. Its fibres originate in the motor nucleus of this nerve in the dorsal part of the pons, where motor fibres of the intermedio nerve arch around it (Fig. 14-14, 16, 46 and Table 14-1).

The abducent nerve emerges on the rostral end of the lateral ventral groove of the medulla oblongata and leaves the cranial cavity together with the maxillary, oculomotor and trochlear nerves, through the round opening or the orbital fissure respectively.

Facial nerve (VII)

The axons of the facial nerve arise from two separate nuclei in the **medulla oblongata.** The motor nucleus is located in the ventral part of the rostral medulla oblongata close to the pons. The fibres from this nucleus run dorsally, around the abducent nucleus to curve ventrally again. The **preganglionic parasympathetic fibres** of the facial nerve originate in the parasympathetic nucleus, which is located caudal to the motor nucleus. The motor and parasympathetic fibres unite just distal to their emergence of the brainstem, lateral to the trapezoid body, to form the roots of the facial nerve. They are joined by sensory fibres from the **geniculate ganglion** (ganglion geniculi). An intermediate portion constitutes the sensory and parasympathetic portion of the facial nerve, while the facial

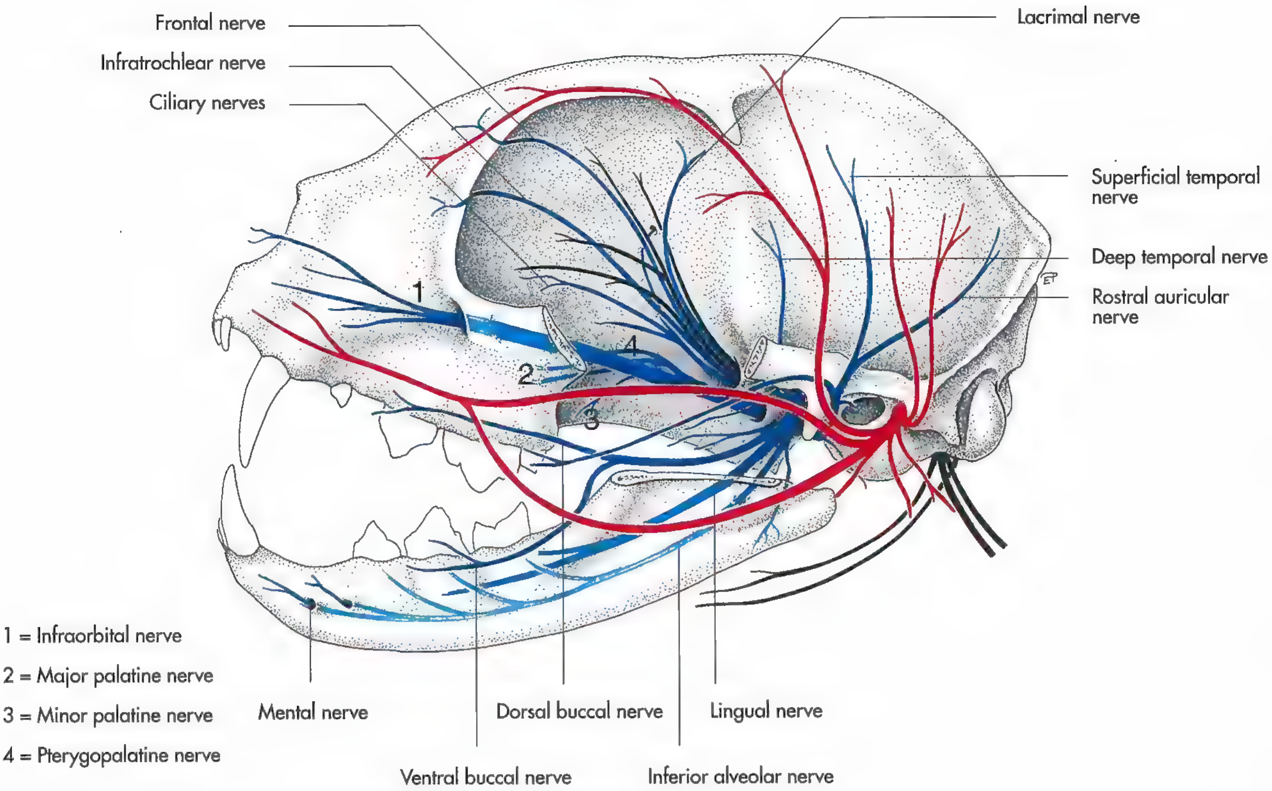


Fig. 14-57. Schematic illustration of the primary branches of the trigeminal nerve in the cat (blue = sensory fibres, red and black see Fig. 14-59) (Schleipp, 1992).

component provides motor innervation to the mimetic musculature.

The **facial nerve** passes to the internal acoustic meatus, accompanied by the vestibulocochlear nerve. It enters the facial canal, a passage within the petrous temporal bone, with a sharp caudal convexity, the genu of the facial nerve, where the nerve is enlarged to form the geniculate ganglion at the summit of the bend.

The bony walls of the facial canal have slit-like openings towards the tympanic cavity. In this location, the facial nerve is separated from the middle ear by only the mucosa lining the tympanic cavity. Thus, facial nerve paralysis may be associated with infections of the middle ear.

The **facial nerve** gives off the **major petrosal nerve** (n. petrosus major), the **stapedial nerve** (n. stapedius) and the **chorda tympani** within the facial canal. The **major petrosal nerve** is composed of mainly parasympathetic fibres, which form synapses in the pterygopalatine ganglion. The postganglionic fibres innervate the lacrimal gland, the nasal glands and the palatine glands.

The **stapedial nerve** provides motor innervation to the like-named muscle of the middle ear. The chorda tympani crosses the tympanic cavity and joins the lingual branch of the trigeminal nerve to provide parasympathetic fibres to the sublingual and mandibular glands as well as gustatory fibres from the taste buds of the rostral two thirds of the tongue.

The nerves detached within the **facial canal** (with the exception of the stapedial nerve) constitute the intermediate component of the facial nerve. After the nerve emerges from the petrous temporal bone through the stylomastoid foramen it is composed by motor fibres only. It provides motor innervation to the entire mimetic musculature, the caudal belly of the digastric muscle and part of the skin of the neck.

The **first branch of the facial nerve** after emerging from the facial canal is the internal caudal auricular nerve, which innervates the small muscles on the back of the external ear and together with a vagal branch, the skin on the inside of the external ear. The **next branch** which arises is the caudal auricular nerve, which curves around the base of the ear, caudally and is motor to the adjacent muscles as well as the platysma muscle of the neck in the cat and the dog. It provides sensory innervation to the skin on the back of the external ear, together with fibres from the first and second cervical nerves.

The **facial nerve** gives off branches to the caudal belly of the digastric muscle and the stylohyoid muscle. In the horse, it sends an additional branch to the caudal detachment of the digastric muscle, the occipitomandibular muscle. The facial nerve

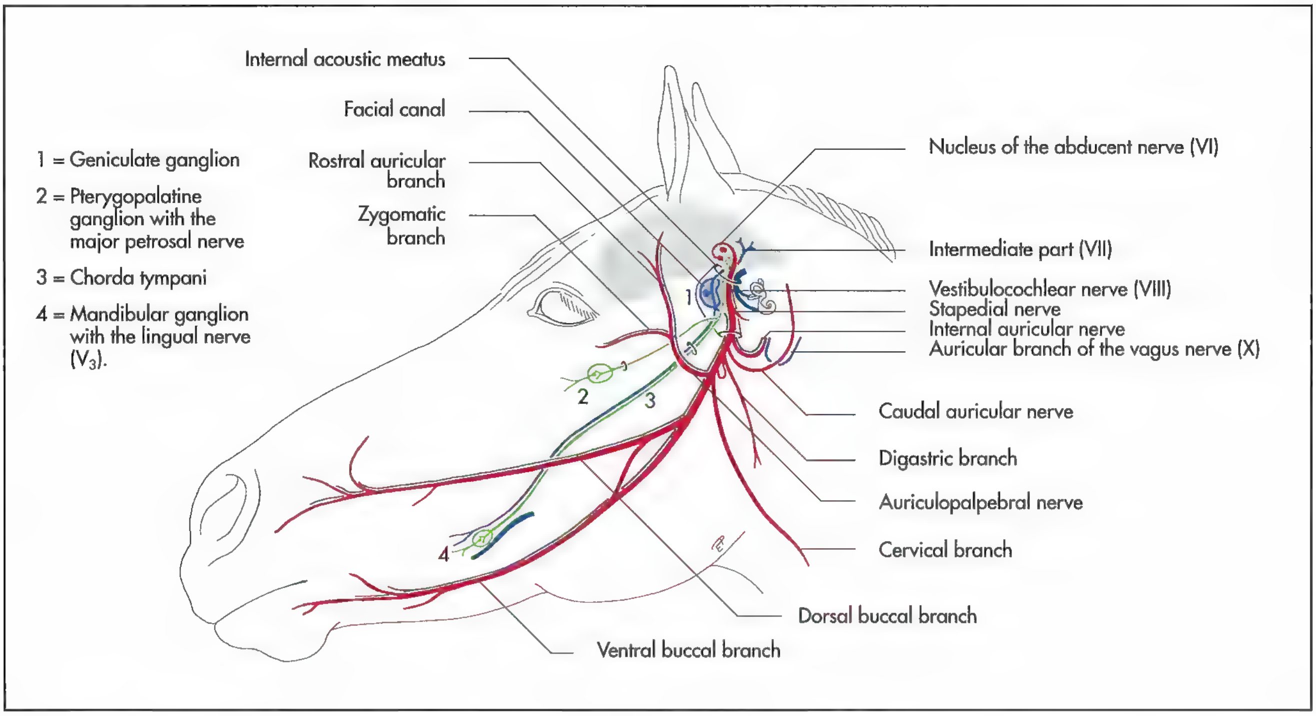


Fig. 14-58. Schematic illustration of the primary branches of the facial nerve in the horse (blue = sensory, red = motor, green = parasympathetic fibres).

innervates the muscles concerned with opening of the mouth. The **auriculopalpebral nerve** arises at the base of the ear. It crosses the zygomatic arch, covered by the parotid gland, and detaches branches to the rostral auricular muscles (rami auriculares rostrales) and a zygomatic branch. Its fibres unite with trigeminal fibres from the auriculotemporal, the lacrimal and the frontal nerves to form a rostral auricular plexus between the eye and the ear from where motor fibres innervate the muscles of the eyelids.

The facial nerve detaches branches to the parotid gland, the parotidoauricular muscle and the cutaneous colli muscle. The branch that innervates the cutaneous colli leaves the facial nerve on its ventral border and unites with fibres of the ventral branches of the first cervical nerve. It is not present in the ox and the sheep.

The **main trunk** reaches a subcutaneous position on the masseter muscle at the rostral border of the parotid gland. Here it terminates by dividing into **buccal branches.** These form a plexus (plexus buccalis), which vary not only among the different species, but also among individuals. From the buccal plexus arise motor branches to the muscles of the cheek, lips and the nares. These are joined by sensory fibres from the auriculotemporal and infraorbital branch of the trigeminal nerve.

The **clinical signs of facial nerve paralysis** clearly depend on the site of the lesion. Lesions, that involve central parts of the nerve, affect the whole facial field, including paralysis of the muscles of the ear, eyelids, nose and lips and lead to loss or reduction of the secretory activity of the lacrimal and salivary glands. More peripheral lesions, that occur in the middle ear or outside the skull lead to unilateral paralysis of the mimetic musculature. It is characterised by asymmetrical drooping of the muzzle and inability to close the eye. Humans show an increased sensitivity to noise (hyperakusis). In horses, the subcutaneous part of the nerve is sometimes damaged by pressure exerted from a tight halter and may paralyse the muscles of the lips and cheeks.

Vestibulocochlear nerve (VIII)

The vestibulocochlear nerve only provides sensory innervation and is composed of the vestibular nerve, that is concerned with balance and the cochlear nerve, that is concerned with hearing (Fig. 14-30, 46 and Table 14-1).

The **vestibular nerve** connects the vestibular apparatus of the inner ear with the brain. The cell bodies of its bipolar neurons are located in the vestibular ganglion and the peripheral fibres arise from the **cristae** (cristae ampullares) and **maculae** (maculae utriculi et sacculi) of the membranous labyrinth. The **vestibular ganglion** is located within the fundus of the internal acoustic meatus and consists of a superior and an inferior part. The afferent fibres of the vestibular component form the vestibular root, that enters the medulla at the trapezoid body, where it passes to the vestibular area with its terminating nuclei (nucleus vestibularis rostralis, spinalis, medialis, lateralis). Part of the fibres pass directly to the cerebellum.

The **cochlear nerve** transmits impulses from the ear to the brain perceived as hearing. It is composed of fibres whose cell bodies are located within the band-shaped **spiral ganglion** within the osseous modiolus of the cochlea. The peripheral processes of these cells end by synapsing with hair cells of

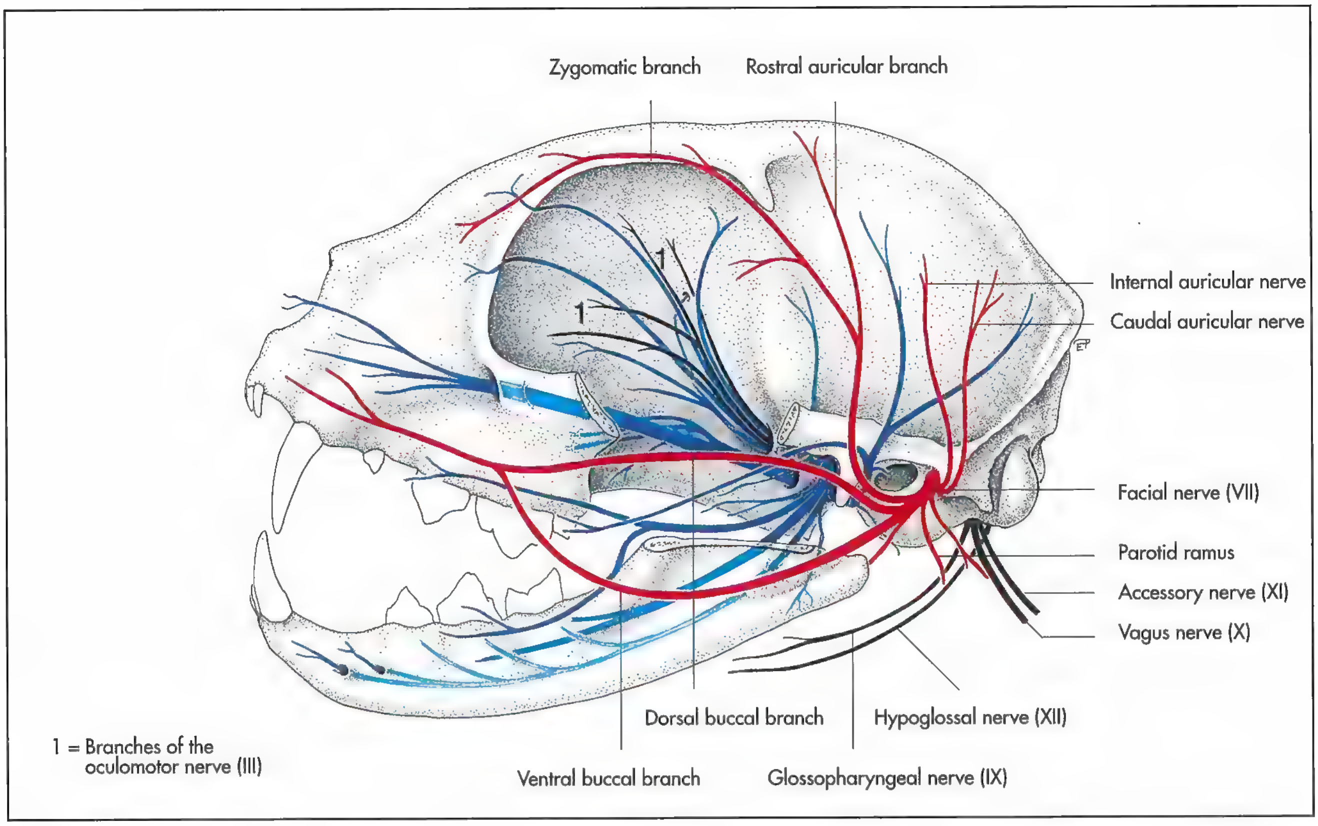


Fig. 14-59. Schematic illustration of the primary branches of the trigeminal nerve in the cat (red = motor, black: fibres of the vagus group and the hypoglossal nerve, blue = sensory fibres, see Fig. 14-59) (Schleipp, 1992).

the **organ of Corti** in the cochlear duct. The central fibres conjoin to form bundles that pass through the perforated cochlear area of the internal acoustic meatus and unite to form the cochlear root of the vestibulocochlear nerve.

The cochlear root combines with the vestibular root and enters the trapezoid body to terminate within the **medulla oblongata** in the ventral and dorsal cochlear nuclei. The two cochlear nuclei are the starting point for the central auditory pathways. After decussating, the fibres pass to the medial geniculate body and the caudal colliculi of the quadrigeminal plate. They ascend with the lateral lemniscus to reach the **cerebral cortex,** where they project onto the **acoustic area of the temporal lobes.**

Glossopharyngeal nerve (IX)

The glossopharyngeal nerve is a mixed nerve, being both, **sensory** and **motor.** Its motor fibres originate in the rostral part of the nucleus ambiguus of the **medulla oblongata.** The **nucleus ambiguus** constitutes a common site of origin for glossopharyngeal and vagal fibres. The parasympathetic fibres arise from the **parasympathetic nucleus of the glossopharyngeal nerve** (Fig. 14-46, 60 and Table 14-1). The glossopharyngeal nerve arises from the ventrolateral aspect of the **medulla oblongata** in close relation to the vagus and the accessory nerve. Some authors refer to these nerves as the **"vagus group".** The glossopharyngeal nerve provides sensory innervation to the middle ear, the caudal third of the tongue and, together with the vagus nerve, the pharynx. It provides motor innervation to the dilator of the pharynx (m. stylopharyngeus caudalis) and probably to the muscles of the soft palate.

The **sensory neurons** have their cell bodies located in the **petrosal ganglion,** which is divided into a proximal part, located intracranially, and a distal part. At the level of the distal ganglion the minor petrosal nerve arises, and gives off small branches to the tympanic plexus and the auditory tube. It leaves the tympanic cavity to end in the **otic ganglion** from which postganglionic secretory fibres continue to the parotid and buccal glands.

The **main trunk** detaches a branch to the carotid sinus (ramus sinus carotici), which innervates baroreceptors in the wall of the carotid bulb and chemoreceptors in the carotid body.

The **glossopharyngeal nerve** terminates by dividing into **lingual** and **pharyngeal branches.** The pharyngeal branches divide within the pharyngeal plexus, to which the vagus also contributes. The lingual branch innervates sensory and parasympathetic fibres to the mucosa of the caudal third of the tongue. There are microscopically small parasympathetic ganglia dispersed along the branches of the glossopharyngeal nerve, especially within the lingual branch. The glossopharyngeal nerve receives sympathetic fibres from the **cranial cervical ganglion.**

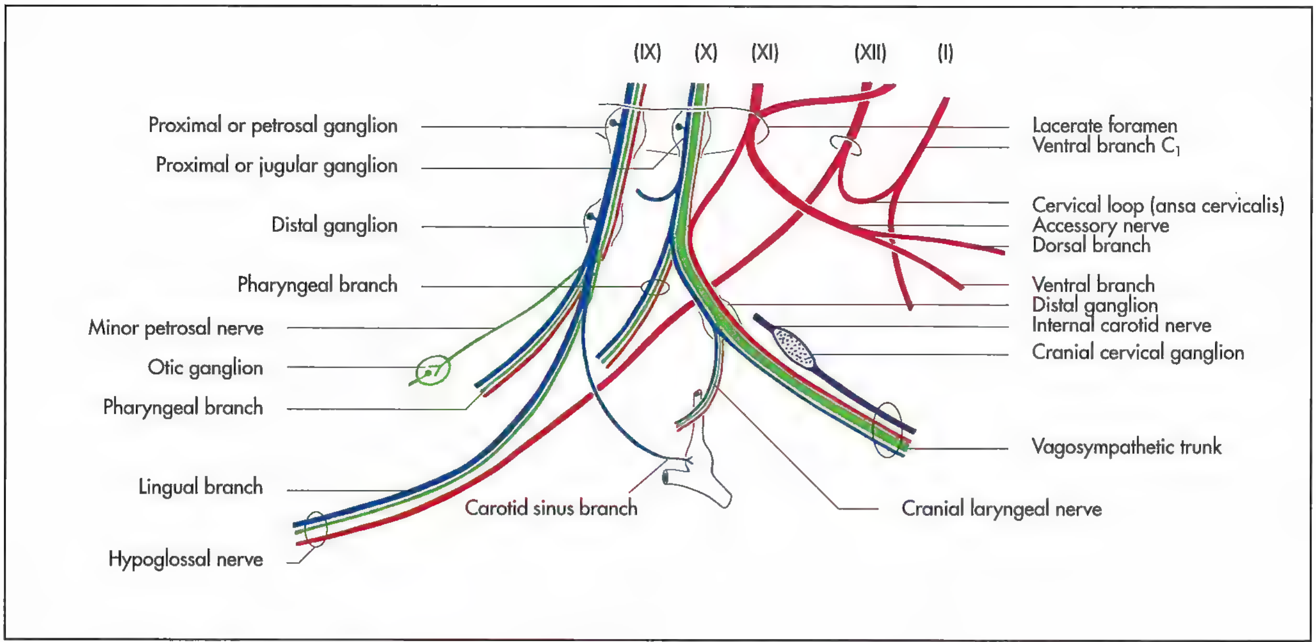


Fig. 14-60. Schematic illustration of the original parts of the vagus group (glossopharyngeal, vagus and accessory nerves) and the hypoglossal nerve, including major ganglia (Budras and Röck, 1997).

In the horse, the glossopharyngeal nerve passes through the medial compartment of the guttural pouch, in a common fold with the hypoglossal nerve. Inflammation of the guttural pouch may cause damage to these nerves, which is characterised by difficulties in swallowing.

Vagus nerve (X)

The vagus nerve is not restricted to the **head,** like the other cranial nerves, but has a widespread distribution to innervate the **viscera of the thoracic** and **abdominal cavities.** It is the largest parasympathetic nerve of the autonomous nervous system (Fig. 14-46, 60, 61 and Table 14-1).

The vagus is a **mixed nerve,** conveying motor, sensory and parasympathetic fibres. The motor fibres arise in the **caudal part of the nucleus ambiguus** of the medulla oblongata and are joined by additional motor fibres from the accessory nerve. The **cell bodies** of the **pseudounipolar sensory neurons** are located in the **proximal ganglion of the vagus nerve** (formerly called jugular ganglion). Their receptors are located in the viscera and their afferent fibres extend to sensory nuclei in the medulla oblongata.

The **parasympathetic preganglionic cell bodies** are located in the **parasympathetic nucleus of the vagus,** which lies immediately caudal to that of the glossopharyngeal nerve in the medulla oblongata. The long preganglionic parasympathetic fibres of this nucleus terminate in the intramural ganglia of the thoracic and abdominal viscera. The parasympathetic branches of the head synapse in the **distal ganglion** (formerly called ganglion nodosum), which is located at the detachment of the cranial laryngeal nerve.

The vagus nerve emerges on the ventrolateral aspect of the medulla oblongata between the glossopharyngeal and the accessory nerve with which it passes through the jugular foramen. The proximal ganglion of the vagus lies within the **jugular foramen.** The vagus nerve detaches a small **meningeal branch** (ramus meningeus) and the auricular branch close to the jugular foramen.

The **auricular branch** joins a branch of the facial nerve to innervate the skin on the inside of the external ear. It is the only branch of the vagus, which innervates the skin. It is hypothesised, that this branch plays a major role with regards to auricular acupuncture.

The next branch to arise is the strong **pharyngeal branch,** which joins the glossopharyngeal nerve in the formation of the **pharyngeal plexus.** This plexus forms a fine network with numerous dispersed groups of nervous cells on the surface of the muscles and in the tela submucosa of the pharynx. These vagus fibres provide sensory innervation to the mucosa of the epiglottis, trachea and esophagus. Branches for the constrictors of the pharynx and the root of the tongue arise from the pharyngeal plexus.

The **cranial laryngeal nerve** arises from the vagus at the **distal ganglion** and marks the end of the cranial portion of the vagus nerve. It passes to the larynx, where it divides into an **external** and an **internal ramus.** The external branch innervates the caudal pharyngeal constrictors, while the internal branch is sensory to the larynx. Before bifurcating the cranial laryngeal nerve detaches the depressor branch, that runs either alone or together with the **vagosympathetic trunk** to the **cardiac plexus,** where its action is to slow the heart rate.

The vagus nerve receives **sympathetic fibres** from the **cranial cervical ganglion.** The distal ganglion of the vagus nerve is visible macroscopically in the dog, cat and pig, while in the horse, ox and sheep is consists of several dispersed cell bodies and requires a microscopic identification. In the goat both discrete and diffuse ganglia occur in different individuals.

The **cervical part of the vagus nerve** begins after the detachment of the cranial laryngeal nerve. It continues along the neck, dorsolateral to the common carotid artery enclosed in a common fascial sheath with the sympathetic trunk, constituting the **vagosympathetic trunk.** At the thoracic inlet, the vagus separates from the sympathetic trunk, proximal to the **middle cervical ganglion.**

The **thoracic portion of the vagus nerve** continues ventral to the subclavian artery to enter the mediastinum, where it detaches cardiac branches, that pass to the cardiac plexus, together with sympathetic fibres from the middle cervical ganglion and the stellate ganglion.

The **large caudal (recurrent) laryngeal nerve** is detached within the thorax. The **right caudal laryngeal nerve** arises at the level of the **arterial costocervical trunk.** It turns around the **right subclavian artery** and ascends along the trachea to end at the larynx. The **left vagus** gives rise to the **left caudal (recurrent) nerve** at the level of the **Botalli's ligament.** It arches around the aorta, where it comes in close contact with the **tracheobronchial lymph nodes.** It continues cranially along the trachea, medial to the common carotid artery to the larynx. Its axons are one of the longest found in the body.

The **two caudal laryngeal nerves** are **motor** to all muscles of the larynx, except the **cricothyroid muscle** and sensory to the mucosa of the caudal part of the larynx. They detach cardiac branches shortly after their origin and small branches to the trachea and esophagus along their cervical passage. Paralysis of the left caudal laryngeal muscle leads to a condition, known as **"roaring"** in the horse.

The vagal trunk continues to the root of the lung, where it divides into **dorsal** and **ventral branches,** which unite with their counterparts from the opposite side of the esophagus to form the **dorsal** and **ventral vagal trunks,** respectively. The dorsal and ventral branches give off bronchial branches.

The dorsal and ventral vagal trunks pass through the esophageal opening of the diaphragm and continue as the **abdominal vagus nerve.** Upon reaching the abdominal cavity, it spreads out to join the sympathetic fibres in the formation of neural plexus, responsible for the innervation of the visceral organs.

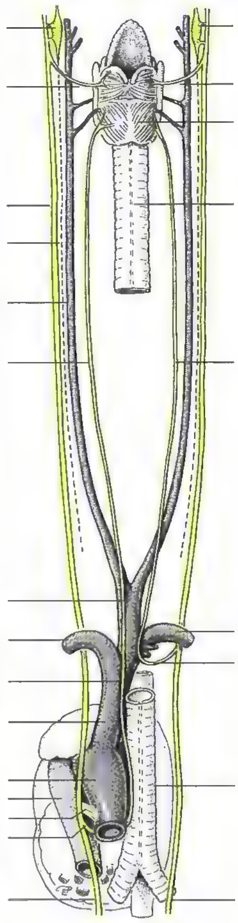


Fig. 14-61. Schematic illustration of the caudal (recurrent) laryngeal nerves of the horse (Grau 1974).

Accessory nerve (XI)

The accessory nerve is also **part of the vagus group.** At its origin it consists of **motor fibres** only, but receives sympathetic fibres from the **cranial cervical ganglion.** It is formed by two roots (Fig. 14-46, 60, 62 and Table 14-1). The fibres of the cranial root take their origin in the **caudal part of the nucleus ambiguus** of the medulla oblongata and leave the accessory nerve to join the vagus nerve.

The fibres of the spinal root have their cell bodies in the **nucleus of the accessory nerve,** which is located in the cervical part of the spinal cord. These leave the spinal cord on the lateral aspect and combine in a trunk that runs along the spinal cord to enter the cranial cavity through the foramen magnum. The accessory nerve exits from the skull with the glossopharyngeal nerve and the vagus, through the jugular foramen. It divides in **ventral** and **dorsal branches** ventral to the wing of the atlas. The dorsal branch passes caudodorsally between the brachiocephalic and the splenius muscle to innervate the covering brachiocephalic (except the cleidobrachial muscle), the omotransverse and the trapezius muscles. The ventral branch innervates the sternocephalic muscle.

Hypoglossal nerve (XII)

The fibres of the hypoglossal nerve originate in the **hypoglossal nucleus** of the **caudal medulla.** They emerge lateral to the pyramids and pass through the dura mater. Their combined trunk leaves the cranial cavity through the hypoglossal canal (Fig. 14-46, 59, 60 and Table 14-1).

It passes rostrally between the vagus and accessory nerve to reach the tongue, where it divides into **deep** and **superficial branches.** It innervates both extrinsic and intrinsic muscles of the tongue.

In the horse, it passes through the medial compartment of the guttural pouch, in a common fold with the glossopharyngeal muscle. It crosses the internal carotid artery and runs parallel with the linguofacial trunk to the root of the tongue.

Tab. 14-1. Summary of the areas of innervation of the cranial nerves.

Nerve	Innervation motor	sensory	parasympathetic
Olfactory nerve (I)		Sense of smell	
Optic nerve (II)		Sight	
Oculomotor nerve (III)	Superficial levator muscle of eyelid and all the muscles of the eyeball apart from the dorsal oblique muscle of eyeball and lateral straight muscle of eyeball		Ciliary muscle and pupillary sphincter muscle
Trochlear nerve (IV)	Dorsal oblique muscle of eyeball		
Trigeminal nerve (V) **– Ophthalmic nerve (V_1)** – Frontal nerve – Lacrimal nerve – Nasociliary nerve		Eyeball, conjunctiva, skin in the eye region, olfactory mucosa, parts of the frontal sinus	By the intermedio-facial nerve for the lacrimal gland
– Maxillary nerve (V_2) – Zygomatic nerve		Skin of the temporal and parietal region, lower eyelid	
– Pterygopalatine nerve – Caudal nasal nerve – Major palatine nerve – Minor palatine nerve		Mucosa of the nasal cavity, maxillary cavity, hard and soft palate	Fibres from the inter-mediofacial nerve for the lacrimal gland
– Infraorbital nerve		Teeth of the upper jaw, skin of the nose and upper lip	
– Mandibular nerve (V_3) – Masticator nerve	Masseter muscle Temporal muscle		
– Medial and lateral pterygoideus nerve	Lateral and medial pterygoid muscle Tensor tympani muscle		
– Buccal nerve		Buccal mucosa	Fibres from the glosso-pharyngeal nerve for the buccal glands, parotid gland
– Auriculotemporal nerve		Skin in the facial region,	
– Inferior alveolar nerve	Mylohyoid muscle and rostral part of the digastric muscle	teeth in the lower jaw, lower lip	
– Lingual nerve		First two thirds of the lingual mucosa	Fibres from the inter-medio facial nerve (chorda tympani) for the sub-lingual glands and mandibular gland
Abducent nerve (VI)	Lateral straight muscle of eyeball Lateral quarter of the retractor muscle of eyeball		

Tab. 14-1. (Continuation)

Nerve	Innervation motor	sensory	parasympathetic
Facial nerve (VII)			
– Stapedius nerve	Stapedius muscle		
– Caudal auricular nerve	Muscles for the pinna of the ear	Skin of the pinna of the ear	
– Auriculopalpebral nerve	Muscles for the eyelids		
– Cervical branch	Muscles for the skin on the neck		
– Digastric branch	Caudal part of the digastric muscle		
– Buccal branches	Facial muscles (mimic)		
– Intermediate part (chorda tympani and major petrosal nerve)		Lingual mucosa	Lacrimal gland, glands of nasal and palate mucosa, sublingual gland and mandibular gland
Vestibulocochlear nerve (VIII)		Balance and hearing	
Glossopharyngeal nerve (IX)		Carotid body (glomus caroticum)	Parotid gland and Buccal glands
– Pharyngeal branch	Caudal stylopharyngeal muscle Pharynx		
– Lingual branch	Levator muscle and tensor muscle of soft palate	Caudal third of the tongue	
Vagus nerve (X)			
Cranial part			
– Auricular branch		Skin on in inside of the pinna of the ear	
– Cranial laryngeal branch	Cricothyroid muscle Larynx		
– Depressor nerve			Cardiac plexus
Cervical part connected to the sympathetic trunk			
Thoracic part			
– Right caudal laryngeal nerve around the right costo-cervical trunk	All laryngeal muscles apart from the cricothyroid muscle		Organs in the pectoral cavity
– Left caudal laryngeal nerve around the aorta			
– Dorsal vagal trunk			
– Ventral vagal trunk			
Abdominal part			Organs in the abdominal cavity
Accessory nerve (XI)			
– Dorsal branch	Brachiocephalic muscle Trapezius muscle Omotransverse muscle		
– Ventral branch	Sternocephalic muscle		
Hypoglossal nerve (XII)	Lingual musculature		

The sympathetic innervation of several cranial organs is achieved via the cranial cervical ganglion

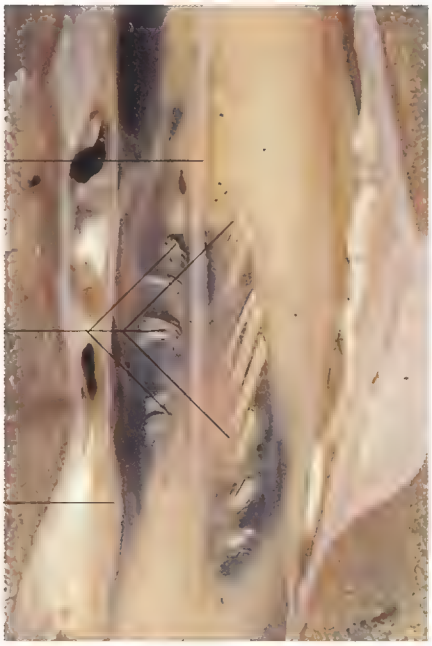


Fig. 14-62. Spinal root of the accessory nerve of an ox (courtesy of PD Dr. J. Maierl, Munich).

Fig. 14-63. Roots of a cervical spinal nerve of an ox (courtesy of PD Dr. J. Maierl, Munich).

Infectious diseases or idiopathic lesions of the guttural pouch can lead to damage of this nerve and are characterised by paralysis of the tongue.

Spinal nerves (nervi spinales)

The number of spinal nerve pairs in each section of the vertebral column corresponds to the number of vertebrae with the exception of the cervical spine and the tail. The first cervical nerve passes through the lateral vertebral foramen of the atlas, while the succeeding cervical nerves exit in front of the corresponding vertebra and the last cervical nerve exits between the seventh cervical vertebra and the first thoracic vertebra, hence there are eight cervical spinal nerves for seven cervical vertebrae. In the coccygeal region, there are fewer nerves than vertebrae (Fig. 14-36 and Table 14-1).

Each spinal nerve originates from the **spinal cord** with a **dorsal** and a **ventral root.** The two roots unite within the vertebral canal to form the spinal nerve. Close to the union of the two roots the dorsal root carries the spindle-shaped **spinal ganglion,** that consists of the cell bodies of afferent, **pseudounipolar neurons** (Fig. 14-64 and Table 14-1).

The **dorsal root** is composed of **afferent fibres,** while the **ventral root** is composed of **efferent motor** and **autonomous fibres.** The resulting mixed spinal nerve exits through the intervertebral foramen and divides almost at once into dorsal and ventral branches.

The **dorsal branch** further divides into a **medial branch** for the innervation of the muscles of the back, that are located dorsal to the transverse vertebral processes and a **lateral branch** for the skin of the back. Cutaneous segments, which are innervated by a particular spinal nerve, are designated dermatomes. The **autonomous component** of their innervation is responsible for so-called Head zones, where certain inner organs are projected onto the skin. The dermatomes of the more caudal spinal nerves extend further ventrally, while the extent of the cranial ones are restricted to the more dorsal parts of the body wall.

The **larger ventral branch** innervates the muscles ventral to the transverse processes and the remaining skin, including the limbs. It usually divides into **two primary branches,** the first one arises in the middle of the abdomen and the second close to the linea alba. The ventral branches of the last three cervical vertebrae and the first two thoracic nerves form the **brachial plexus** that gives rise to the nerves of the forelimb. The last three lumbar nerves and the first two sacral nerves form the **lumbosacral plexus** of the hindlimb.

Cervical nerves (nervi cervicales)

The dorsal and the ventral branches of the cervical nerves communicate with each other to form the dorsal and ventral cervical plexus, respectively (Fig. 14-64).

The **ventral branch of the first cervical nerve** joins the hypoglossal nerve in the **cervical loop** (ansa cervicalis), from which branches arise for the innervation of the long muscles of the hyoid apparatus: the sternohyoid, the sternothyroid and the omohyoid muscle.

The **ventral branch of the second cervical nerve** detaches the great auricular nerve (n. auricularis magnus), which joins the caudal auricular branch of the facial nerve in the innervation of the caudal part of the external ear.

The **ventral roots of the fifth** (cat: fourth) to **seventh cervical nerves** form the **phrenic nerve,** that runs caudally within the mediastinum to innervate the diaphragm.

The **supraclavicular branches** also arise from ventral branches and innervate the skin over the shoulder joint.

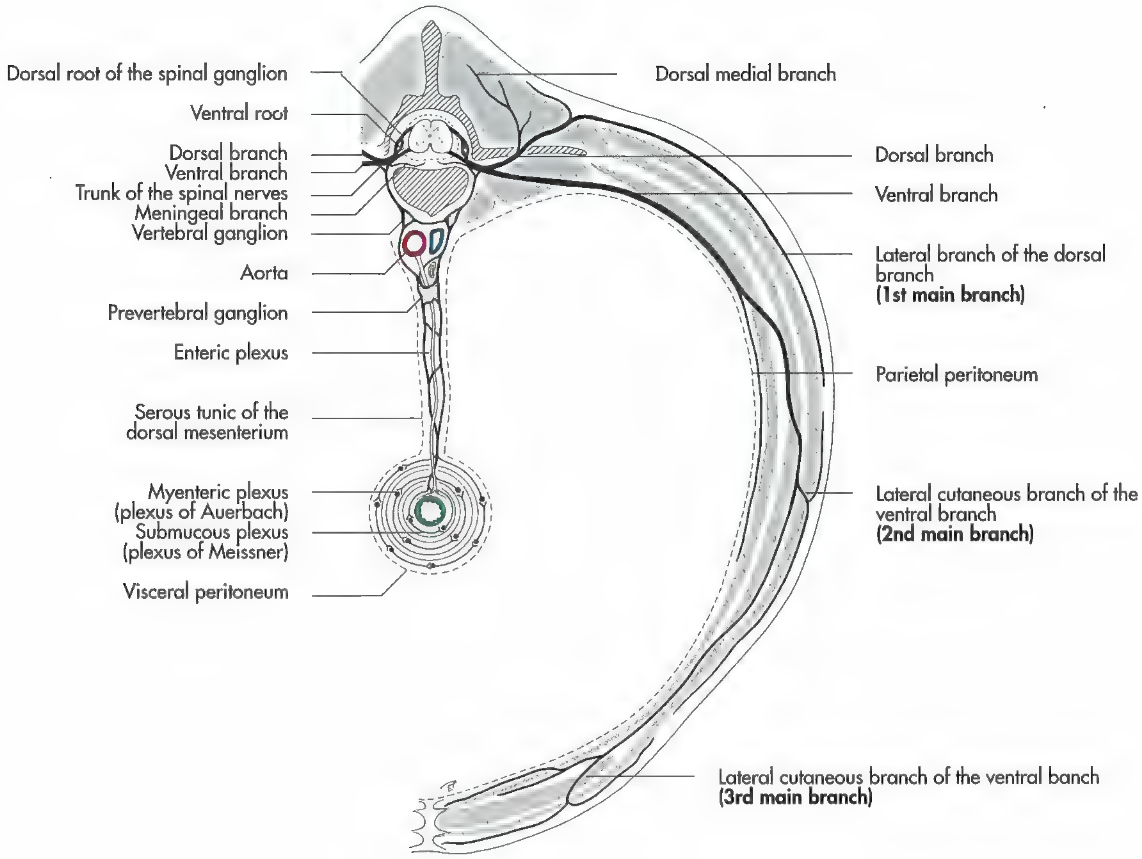


Fig. 14-64. Schematic illustration of a spinal nerve of the horse (Grau, 1974).

Brachial plexus (plexus brachialis) and nerves of the thoracic limb

The brachial plexus is usually formed by the ventral branches of the **sixth, seventh** and **eight cervical** and the **first** and **second thoracic spinal nerves.** It gives origin to the nerves that innervate the muscles and skin of the thoracic limb, parts of the shoulder girdle musculature and the lateral wall of the thorax and abdomen (Fig. 14-65 to 71 and Table 14-2 to 4).

The exceptions are the brachiocephalic, the omotransverse, the rhomboid, and the trapezius muscles and the skin over the upper shoulder region. These structures are supplied by the dorsal and ventral branches of the cervical and thoracic spinal nerves.

The **branches of the brachial plexus** are usually **mixed,** since the cerebrospinal fibres are joined by autonomous fibres from the stellate ganglion.

The plexus is located **cranial to the first rib** between the long muscle of the neck and the scaleni muscles. The roots of the plexus reach the medial aspect of the shoulder by passing between the middle and ventral portion of the scalenus (Fig. 14-2 to 4). In carnivores the roots pass ventral to the middle scalene muscle. Several branches of the plexus have very restricted local distributions on the wall of the thorax and are of no clinical importance. These nerves will only be described briefly (Fig. 14-64 and 65, Table 14-3):

- Long thoracic nerve (n. thoracicus longus),
- Thoracodorsal nerve (n. thoracodorsalis),
- Lateral thoracic nerve (n. thoracicus lateralis),
- Cranial and caudal pectoral nerves (nn. pectorales craniales et caudales) and
- Subscapular nerves (nn. subscapulares).

The **long thoracic nerve** passes caudally on the lateral surface of the thoracic part of the ventral serrate muscle, which it innervates. The cervical portion of this muscle is supplied by cervical spinal nerves.

The **thoracodorsal nerve** arises from the last cervical spinal nerve, runs caudally, crosses the major teres muscle

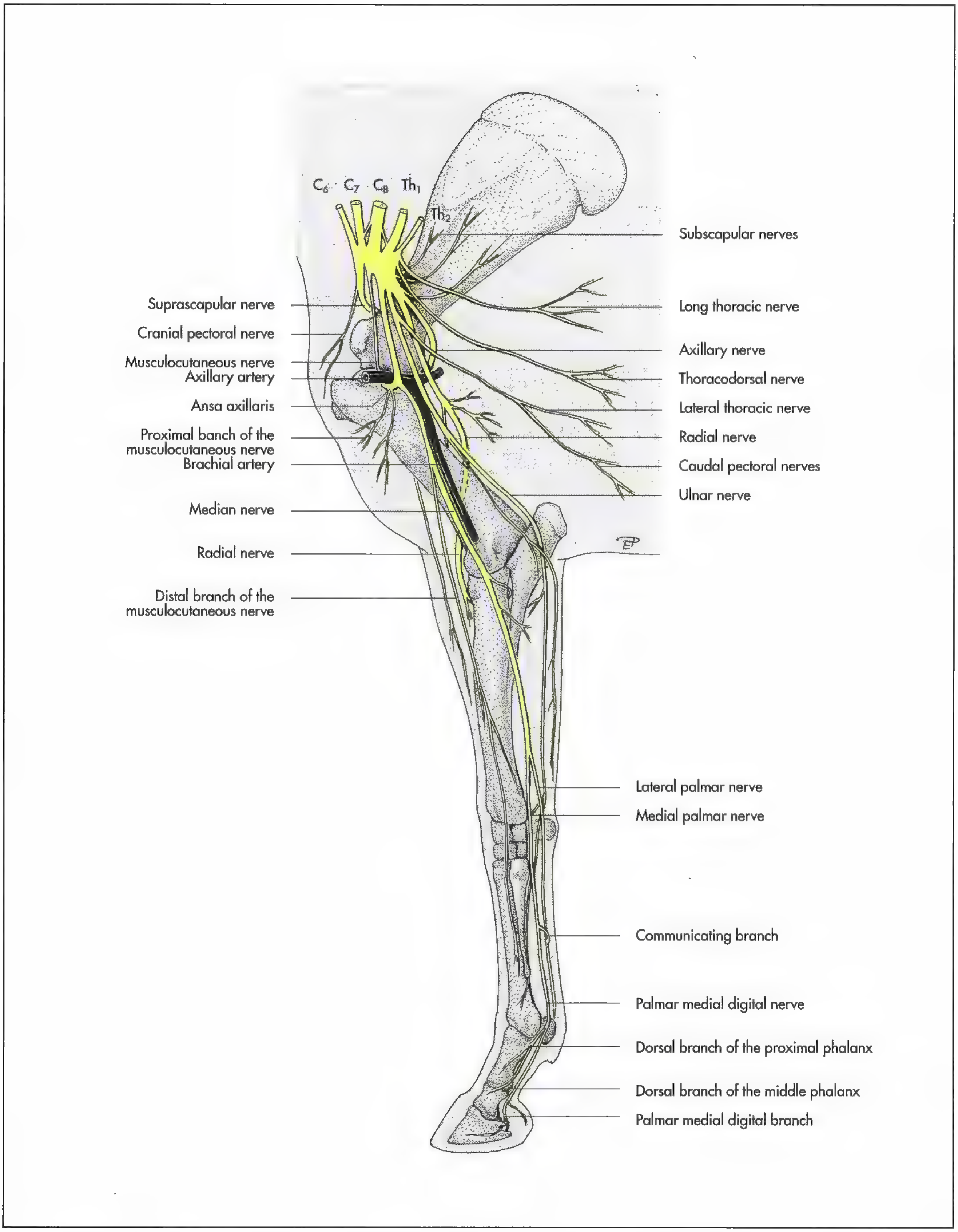
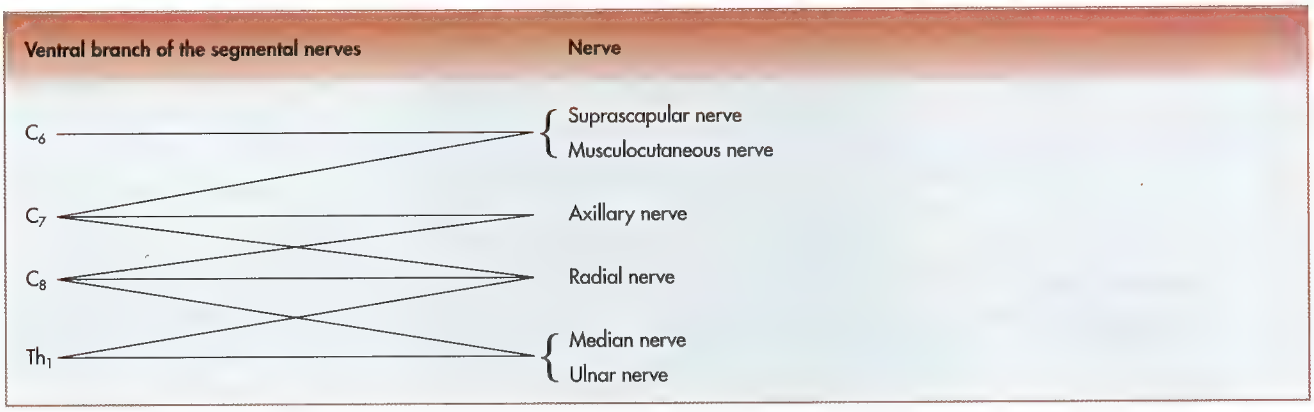


Fig. 14-65. Brachial plexus and its branches of the right thoracic limb of the horse, medial aspect (Ellenberger and Baum, 1943).

Tab. 14-2. Composition of the most important nerves of the brachial plexus (Habel, 1978).



and branches out on the medial surface of the broadest muscle of the back, which it innervates.

The **lateral thoracic nerve** arises from caudal parts of the plexus (C_8 and Th_1) and passes along the broadest muscle of the back to innervate the abdominal part of the cutaneous muscle. Some of its branches unite with adjacent intercostal nerves to form the intercostobrachial nerve, which innervates the skin caudal to the triceps and over the ventral thorax and abdomen. Sensory fibres are contributed by the intercostal nerves.

The **cranial** and **caudal pectoral nerves** arise from the cranial part of the plexus and innervate the pectoral muscles. The cranial pectoral nerves innervate the superficial pectoral muscle and in ungulates the subclavian muscle. The caudal pectoral nerves pass caudoventrally to the deep pectoral muscle.

The **subscapular nerves** arise either as individual nerves or as a plexus from the cranial part of the brachial plexus. It innervates the cranial and middle part of the subscapular muscle.

The following three nerves have a relatively limited distribution, but are of considerable functional importance (Fig. 14-65, 66 and Table 14-2 to 4):

- Suprascapular nerve (n. suprascapularis),
- Musculocutaneous nerve (n. musculocutaneus),
- Axillary nerve (n. axillaris).

Suprascapular nerve

The suprascapular nerve passes between the subscapular and the suprascapular muscles to reach the cranial margin of the neck of the scapula, around which it winds to the lateral aspect of the bone where it innervates the supraspinous and infraspinous muscles. Because of its close relationship to the bone, it is vulnerable to traumatic damage. Paralysis of the suprascapular nerve usually results in atrophy of the muscles it innervates. In the standing animal, the shoulder is abducted and this becomes more pronounced during locomotion **("shoulder slip")**. The condition occurs most commonly in horses, in which it is clinically known as **"Sweeney"**. It is usually caused by trauma, when the nerve is stretched against the scapula by over-abduction of the limb or violent retraction.

Musculocutaneous nerve

The musculocutaneous nerve arises caudal to the suprascapular nerve from the brachial plexus. It runs parallel to the median nerve, with which it joins in ungulates to form a **loop** around the **axillary artery** (ansa axillaris). In the proximal part of the humerus, it branches to form the proximal muscular branch, which passes cranially between the humerus and the coracobrachial muscle to innervate the latter and the biceps muscle. The musculocutaneous nerve divides again to form the median nerve in the distal third of the upper arm, which innervates the brachial muscle and the skin on the medial aspect of the antebrachium.

Lesions of the musculocutaneous nerve are uncommon but would paralyse the main flexors of the elbow. However, this could be compensated for by the radial nerve, which also contributes to the innervation of the brachial muscle. Loss of sensation of the skin on the medial aspect of the antebrachium will aid in the diagnosis of musculocutaneous nerve damage.

Axillary nerve

The axillary nerve passes caudal to the shoulder joint to the lateral aspect of the limb. On the medial side, it innervates the teres major muscle and the caudal third of the subscapular muscle. It also innervates the capsular and teres minor muscles. It branches to innervate the deltoid muscle and gives off a branch to the cleidobrachial muscle. Its cutaneous branch reaches a subcutaneous position on the ventral border of the deltoid muscle and innervates the skin on the cranial aspect of the arm and antebrachium (Fig. 14-69).

The remaining three nerves of the thoracic limb extend from the brachial plexus all the way to the apex of the limb (Fig. 14-65, 66 and Table 14-2 to 4):

- Radial nerve (n. radialis),
- Median nerve (n. medianus),
- Ulnar nerve (n. ulnaris).

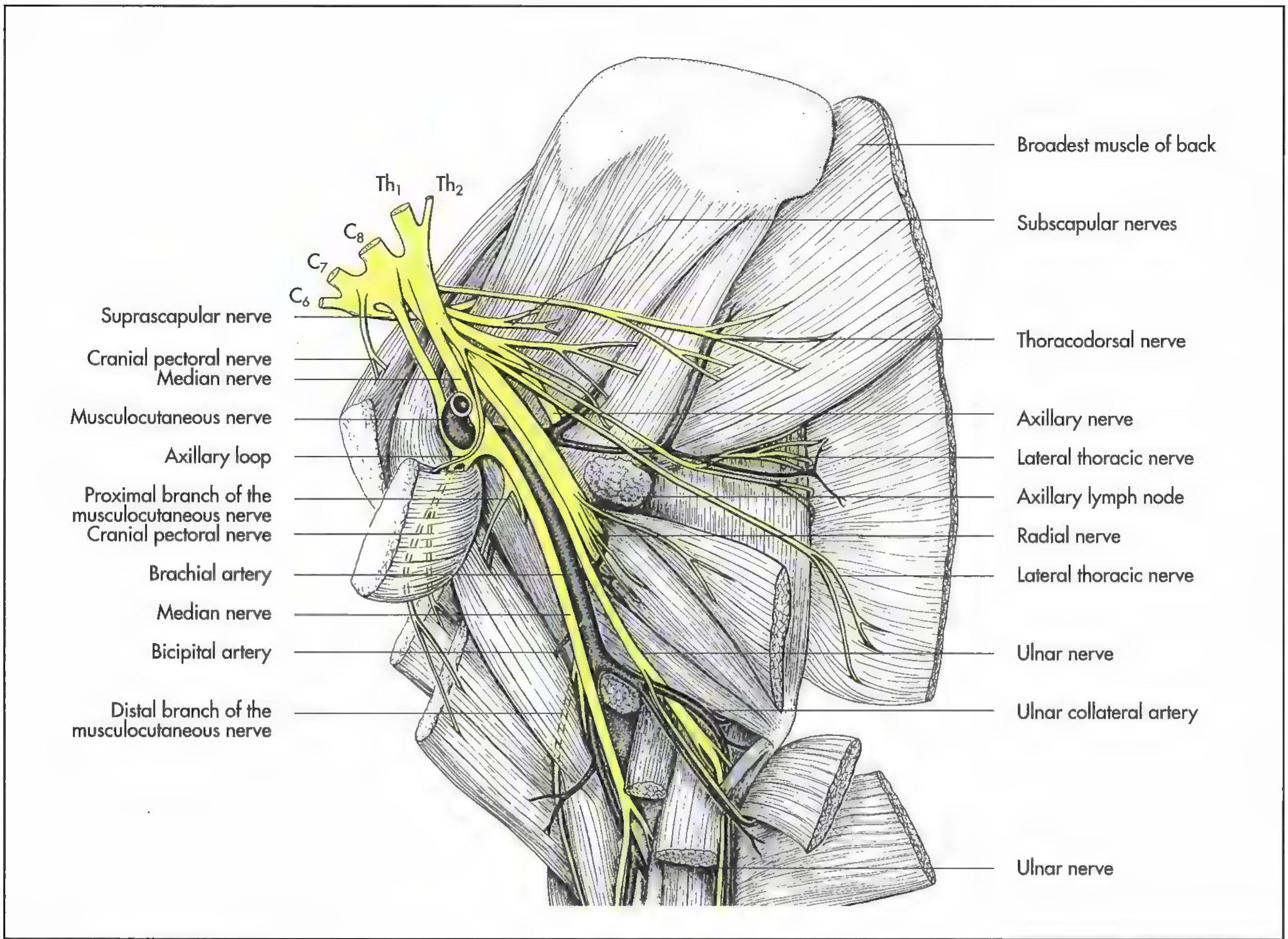


Fig. 14-66. Brachial plexus of the right thoracic limb of the horse, medial aspect.

Radial nerve

The radial nerve receives most of its fibres from the eighth cervical nerve. It is the **largest nerve** of the brachial plexus and has the **widest distribution.** It innervates all extensor muscles of the thoracic limb, except those of the shoulder joint. It innervates the skin over the lateral aspect of the limb, extending from the antebrachium to the apex of the limb in all domestic mammals other than the horse, where it ends distal to the carpus (Fig. 14-65 to 71).

The **radial nerve** runs distally, caudal and parallel to the brachial artery, before passing between the long and medial

Tab. 14-3. Summary of the innervation areas of the brachial plexus nerves, supplying the lateral side of the thorax.

Nerve	Innervation motor	sensory
Cranial pectoral nerve	Superficial pectoral muscle	
	Subclavian muscle	
Caudal pectoral nerves	Deep pectoral muscle	
Long thoracic nerve	Thoracic part of the ventral serrate muscle	
Thoracodorsal nerve	Broadest muscle of back	
Lateral thoracic nerve Intercostobrachial nerve	Cutaneous muscle	Skin lateral on the thorax and covering the triceps muscle of forelimb

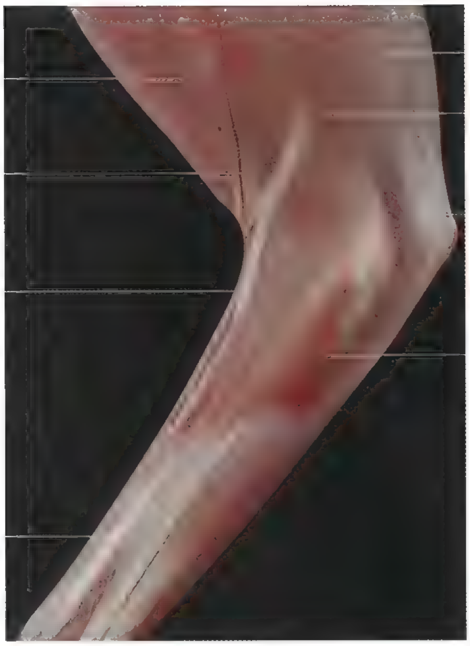


Fig. 14-67. Left forelimb of a cat, showing the radial nerve, lateral aspect.

heads of the triceps muscle to follow the spiral groove of the humerus to the craniolateral aspect of the limb. On its course, it innervates branches to the extensor muscles of the elbow joint (triceps of the forelimb, anconeus, tensor of the antebrachial fascia). In the distal third of the humerus, it detaches its cutaneous branch (ramus cutaneus antebrachii) to the skin of the antebrachium.

Clinical signs of radial nerve paralysis depend on the site of injury. The more proximal the damage, the more severe the syndrome and the more grave the prognosis. **Avulsion of the brachial plexus,** seen in animals after a car accident, results in a numerous neurological deficits, which rarely resolve. Damage to the radial nerve proximal to the middle of the arm usually results in paralysis of the extensors of the elbow, paralysis of the carpal and digital extensors and anaesthesia of the skin territory. The affected animal cannot fix its elbow joint, thus revealing a non-weightbearing lameness with dragging of its toes. Injury to the radial nerve in the distal part of the radius results in paralysis of the carpal and digital extensors (extensor carpi radialis, extensor carpi ulnaris, common digital extensor), the affected animal knuckles over and tries to stand on the dorsal aspect of the toe.

Tab. 14-4. Summary of the innervation areas of the brachial plexus nerves, supplying the proximal muscles of the forelimb.

Nerve	Innervation motor	sensory
Suprascapular nerve	Supraspinous muscle Infraspinous muscle	
Axillary nerve	Flexors of the shoulder joint: Deltoid muscle Major teres muscle Minor teres muscle Cleidobrachial muscle	Skin on the front surface of the antebrachium
Subscapular nerves	Subscapular muscle	
Musculocutaneous nerve	Coracobrachial muscle Biceps muscle of forelimb Brachial muscle of forelimb, partly	Skin medial of the antebrachium

Fig. 14-68. Cutaneous branches of the right antebrachium of a horse, medial aspect (courtesy of Dr. R. Macher, Vienna).

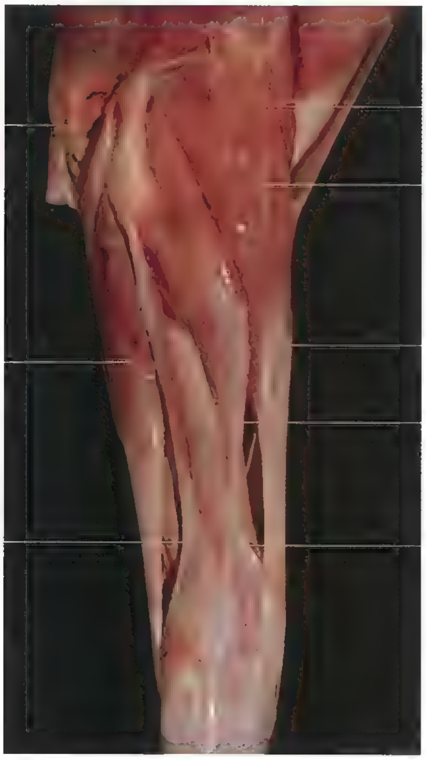


Fig. 14-69. Cutaneous branches of the right antebrachium of a horse, lateral aspect (courtesy of Dr. R. Macher, Vienna).

Tab. 14-5. Summary of the innervation areas of the nerves supplying the tip of the forelimb.

Nerve	Innervation motor	sensory
Radial nerve	All extensors of the forelimb with exemption of the shoulder joint muscles Triceps muscle of forelimb Anconeus muscle Tensor muscle of antebrachial fascia Brachial muscle of forelimb (partly) Radial extensor muscle of carpus Common digital extensor muscle Lateral digital extensor muscle Ulnar extensor muscle of carpus (flexor) Long abductor muscle of first digit Brachioradial muscle Supinator muscle	Skin lateral on the brachium and antebrachium
Median nerve	Radial flexor muscle Round pronator muscle Pronator quadratus muscle Deep digital flexor muscle (partly) Superficial digital flexor muscle (partly)	Skin palmar on the metacarpus and the digits (with ulnar nerve)
Ulnar nerve	Ulnar flexor muscle of carpus Deep digital flexor muscle (partly) Superficial digital flexor muscle Interosseous muscles	Skin caudal on the antebrachium, dorsolateral on the metacarpus and the digit (partly)

Comment: The nerves of the brachial plexus contain motor, sensory as well as vegetative fibres.

Median nerve

After its origin from the brachial plexus, the median nerve runs down the medial surface of the antebrachium. It combines with the musculocutaneous nerve to form a loop around the axillary artery (Fig. 14-65). At the cranial aspect of the elbow joint, the median nerve passes laterally under the round pronator muscle to innervate the large caudal group of flexor muscles of the antebrachium. In the cat, it passes through the supracondylar foramen. It innervates the radial flexor muscle and the deep and superficial digital flexor muscles. Its distribution overlaps with that of the ulnar nerve. In the distal part of the antebrachium it divides into two or more branches, this descends through the carpal canal to innervate most of the structures on the palmar aspect of the distal limb (Fig. 14-71).

Ulnar nerve

The ulnar nerve runs distally on the medial aspect of the antebrachium in close relation to the median nerve and caudal to the brachial artery. It passes caudally at the level of the elbow joint, running under the ulnar head of the ulnar flexor muscle to the ulnar groove on the caudal aspect of the antebrachium (Fig. 14-65 and 66).

Within the antebrachium, it detaches the caudal cutaneous antebrachial nerve to the skin on its caudal aspect. In the proximal part of the antebrachium, it branches to innervate the ulnar flexor muscle and the deep and superficial digital flexor muscles.

A **dorsal branch** arises proximal to the accessory carpal bone and passes dorsally to innervate the skin on the lateral surface of the distal limb. The narrow continuation of the ulnar nerve passes through the carpal canal and innervates muscles, skin and deeper structures of the digit. The distribution within the foot is closely related to that of the median nerve, with which it partly combines (Fig. 14-70 and 71).

Innervation of the distal limb

With the exception of the horse, each digit is supplied by four nerves, two dorsal and two palmar digital nerves (see chapter 18). The axial and abaxial dorsal digital nerves are terminal branches of the superficial branch of the radial nerve, with the exception of the dorsal digital nerves of the most lateral digit, which are branches of the ulnar nerve (Fig. 14-70). The palmar digital nerves of the first, second and third digit arise from the median nerve, while those for the fourth and fifth digit arise from the ulnar nerve.

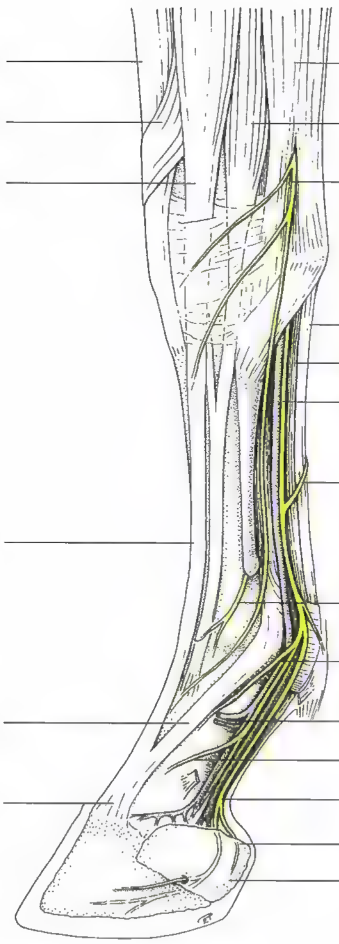


Fig. 14-70. Nerves of the left forefoot of the horse, lateral aspect.

Innervation of the distal limb of the horse

Most of the structures distal of the carpus are supplied by the **medial** and **lateral palmar nerves,** both of which are branches of the **median nerve,** and the **dorsal** and **palmar branches** of the **ulnar nerve.** The median nerve divides into medial and lateral nerves proximal to the carpus (Fig. 14-70 and 71). The lateral palmar nerve detaches a deep branch to the suspensory ligament at the level of the carpus.

The **palmar branches** lie palmar to the metacarpal bone between the suspensory ligament and the digital flexor tendons. In the mid-metacarpal region the medial palmar nerve detaches a communicating branch, that crosses over the superficial digital flexor tendon, where it is usually palpable, to join the lateral palmar nerve.

Just proximal to the metacarpophalangeal joint, the palmar nerves become the **medial** and **lateral digital nerves,** which pass distally, caudal to the like-named artery over the abaxial aspect of the proximal sesamoid bones. Both nerves detach **dorsal branches** at the level of the proximal and middle phalanx. Variations in their distribution pattern are common. **Local anaesthesia of these nerves** plays a major role in the diagnosis of lameness. The nerves are sequentially blocked at different levels from distal to proximal to determine the location of the lesion.

Tab. 14-6. Innervation of the joints of the forelimb.

Shoulder joint	Axillary nerve Suprascapular nerve
Ellbow joint and Carpal joint	Median nerve Ulnar nerve
Fetlock joint and further digital joints	Palmar nerves Digital nerves

Ventral branches of the thoracic nerves

The first two ventral branches of the thoracic spinal nerves contribute to the brachial plexus (Fig. 14-64). Generally, the thoracic ventral branches form the intercostal nerves, which pass ventrally on the caudal aspect of the corresponding rib. The intercostal nerves innervate the intercostal muscles, the transversus thoracis muscle and the rectus thoracis muscle. The last five to ten ventral thoracic branches innervate the abdominal muscles. The ventral branch of the last thoracic nerve is referred to as the costoabdominal nerve. The ventral branches also detach branches to the mammary glands.

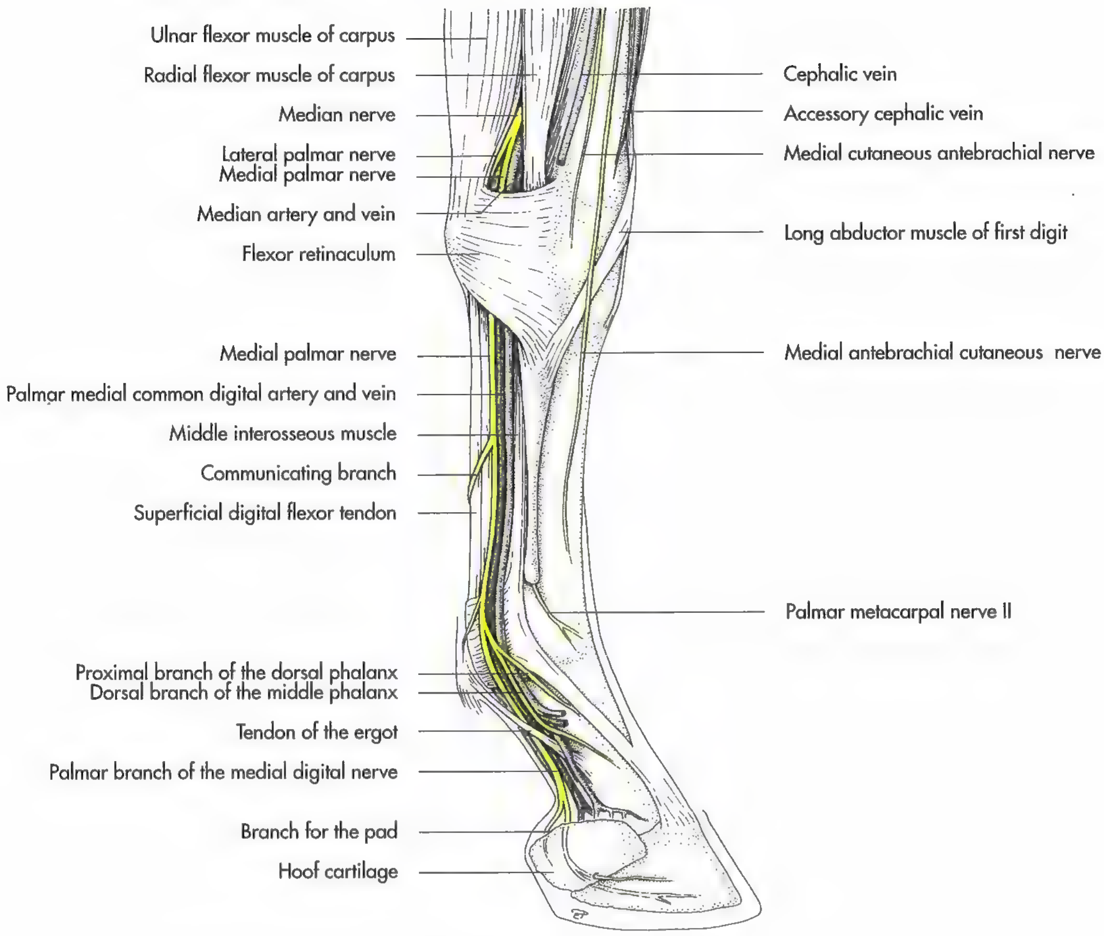


Fig. 14-71. Nerves of the left forefoot of the horse, medial aspect.

Lumbar nerves (nn. lumbales)

The number of the lumbar spinal nerve pairs corresponds to the number of the lumbar vertebrae: six in the horse, pig and ruminants and seven in the dog and cat. Similar to the other spinal nerves, they divide into **dorsal** and **ventral branches** shortly after their passage through the intervertebral foramen. Each dorsal branch typically divides into **medial** and **lateral branches.** The medial branches innervate the muscles of the back, dorsal to the spine and the lateral branches arborize in the skin over the lumbar and rump region. The branches that innervate the rump are termed the **cranial clunial nerves** (nn. clunium craniales).

The **ventral branches** of the **lumbar spinal nerves** interconnect to form the lumbar plexus. Some authors describe the lumbar plexus as being formed by the ventral branches of all lumbar spinal nerves. However, the first three ventral lumbar branches exchange relatively few fibres and are described as individual nerves. The remaining ventral lumbar branches form the **lumbar plexus proper** (plexus lumbalis), that unites with the first and second sacral nerve in the **lumbosacral plexus** (plexus lumbosacralis) (Fig. 14-72 and 73 and Table 14-7 and 8).

The **ventral branches** of the **lumbar spinal nerves** are of considerable clinical importance, since they are often anaesthetised with local anaesthetic to facilitate abdominal and pelvic surgery. These nerves can be identified for injection by palpating the ends of the transverse processes and anaesthetising the nerve, where it runs between the transverse and the internal oblique abdominal muscles.

The following individual nerves arise from the lumbar plexus (Fig. 14-72 and Table 14-7 and 8):

- Iliohypogastric nerve (n. iliohypogastricus),
- Ilioinguinal nerve (n. ilioinguinalis),
- Genitofemoral nerve (n. genitofemoralis),
- Lateral cutaneous femoral nerve (n. cutaneus femoris lateralis),
- Femoral nerve (n. femoralis) and
- Obturator nerve (n. obturatorius).

Iliohypogastric nerve

The iliohypogastric nerve represents the primary ventral branch of the **first lumbar nerve** (Fig. 14-73). It extends to a retroperitoneal position between the tip of the transverse

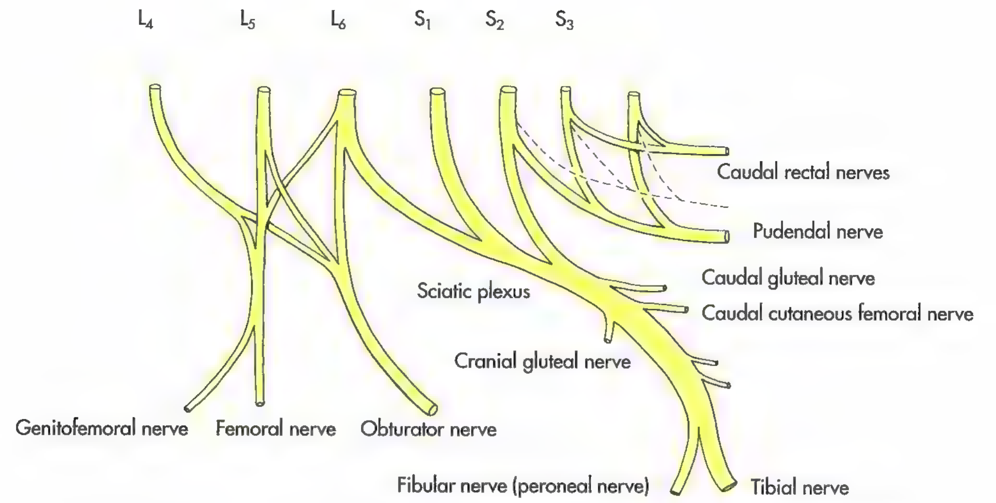


Fig. 14-72. Schematic illustration of the lumbosacral plexus.

processes of the first two lumbar vertebrae. In the cat and the dog, in which there are seven lumbar vertebrae, the first two ventral branches are known as the cranial and caudal iliohypogastric nerves.

Ventral to the transverse processes, the iliohypogastric nerve divides into lateral and medial branches. The **medial branch** passes to the inguinal region. The **lateral branch** passes between the abdominal muscles, which it innervates and detaches two branches to the skin: the lateral cutaneous branch, which innervates a narrow band of skin caudal to the ribs and the medial cutaneous branch, which is innervates the skin over the ventral abdomen, the inguinal mammary glands and the medial side of the thigh, where it combines with the ilioinguinal nerve.

Ilioinguinal nerve

The ilioinguinal nerve is the primary ventral branch of the **second (third in carnivores) lumbar spinal nerve** (Fig. 14-73). Its branching pattern is similar to that of the iliohypogastric nerve. Its lateral cutaneous branch innervates a territory caudal to that of the iliohypogastric nerve, with which it overlaps.

Genitofemoral nerve

The genitofemoral nerve arises from the **third** and **fourth ventral lumbar branches,** the root of the third being larger than that of the fourth (Fig. 14-72 and 73). It runs caudally between the inner lumbar muscles and reaches the inner inguinal ring together with the external iliac artery. Before leaving the abdomen, it detaches a branch to the internal oblique abdominal muscle. It passes through the inguinal canal with the external pudendal artery and vein.

It innervates the skin over the medial aspect of the thigh. It sends branches to the inguinal mammary glands and in the female cat and dog to the skin surrounding the vulva. It also conveys autonomic fibres that regulate milk flow during suckling. In the male, it innervates the prepuce and the scrotum.

Lateral cutaneous femoral nerve

The lateral cutaneous femoral nerve is formed primarily by the ventral branch of the **fourth lumbar nerve** (Fig 14-73). It detaches branches to the inner lumbar muscles and accompanies the caudal branch of the deep circumflex iliac artery through the abdominal wall. It innervates the skin over the lateral aspect of the distal thigh and the stifle joint.

Femoral nerve

The femoral nerve is a **strong nerve,** which detaches branches to the inner lumbar muscles in its proximal portion (Fig. 14-72 and 73). It continues caudally along the iliopsoas and greater psoas muscles and branches to form the saphenous nerve, which enters the femoral canal. The femoral nerve innervates all four heads of the quadriceps muscle. It passes adjacent to the pecten of the os pubis, where it is prone to mechanical damage. Over-extension of the quadriceps muscles, e.g. during recovery from anaesthesia or pelvic fractures are the most common causes of femoral nerve injuries. Damage to this nerve leads to paralysis of the quadriceps, which prevents fixation of the stifle joint and renders the whole limb incapable of supporting weight.

The **saphenous nerve** (n. saphenus) forms muscular branches, which innervate the sartorius, pectineal and gracilis muscles (Fig. 14-73 and 74). It passes through the femoral canal cranial to the femoral artery. In the middle of the thigh, it reaches a subcutaneous position. At the level of the stifle, a small branch accompanies the descending genicular vessels to the stifle joint. The saphenous nerve continues dis-

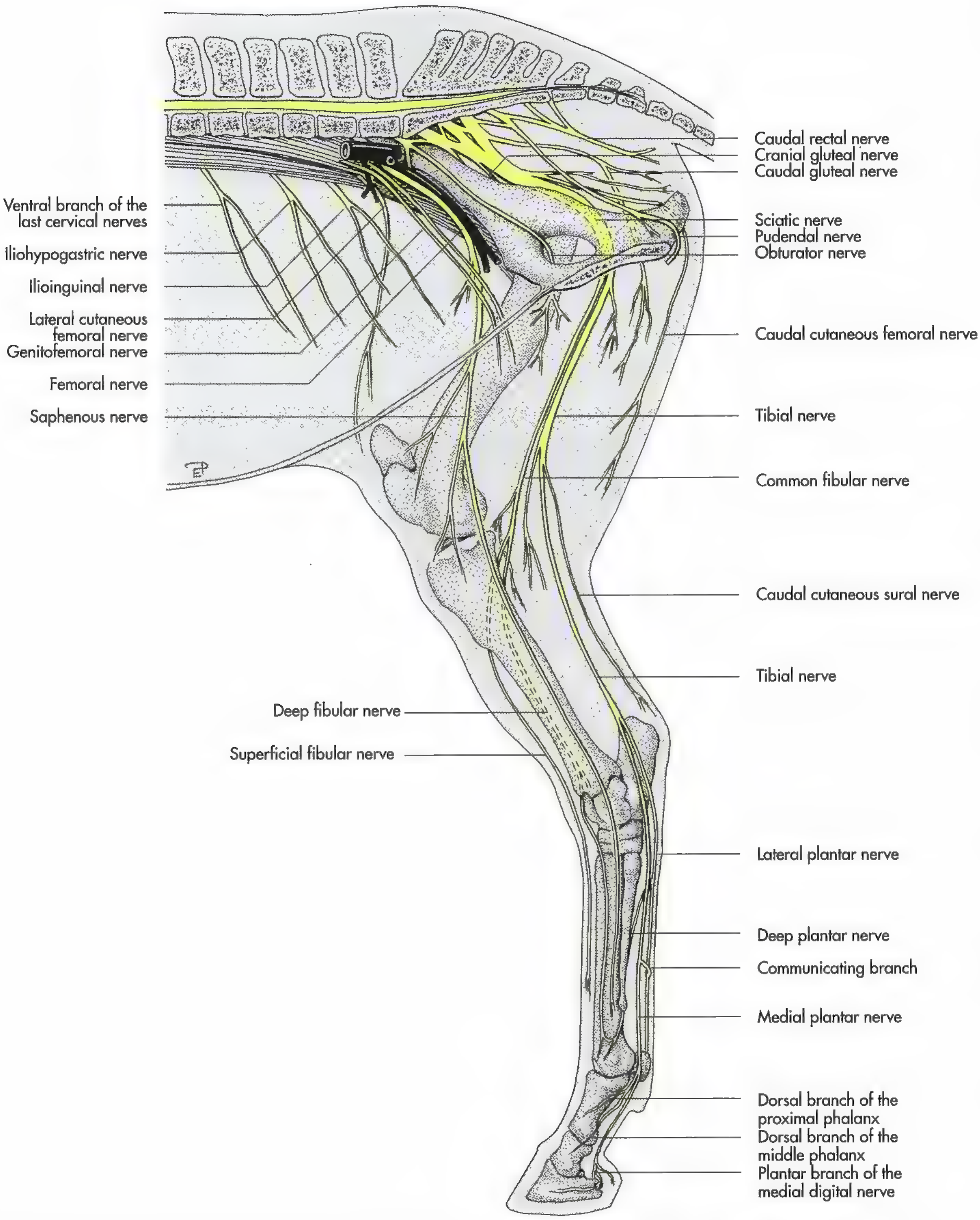
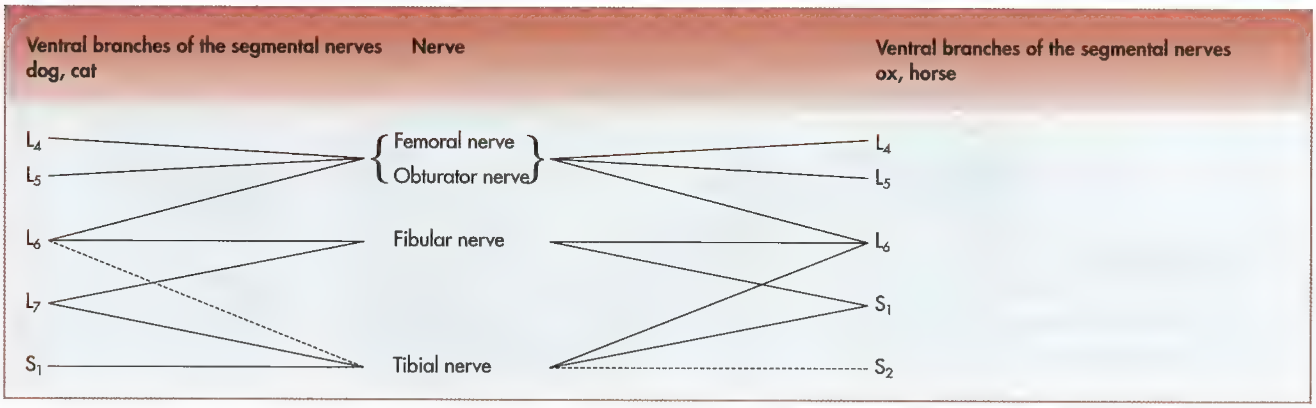


Fig. 14-73. Lumbosacral plexus and nerves of the right hindlimb in the horse, medial aspect (Ellenberger and Baum, 1943).

Tab. 14-7. Composition of the most important nerves of the hindlimb, Habel (1978).



tally, parallel to the like-named artery and the medial saphenous vein to innervate the skin over the medial aspect of the leg, extending from the thigh to the tarsus.

Obturator nerve

The obturator nerve follows the medial aspect of the shaft of the ilium to reach the obturator foramen, through which it leaves the pelvis. It provides innervation to the adductor muscles of the pelvic limb. This group comprises the pectineal, gracilis and external obturator muscles.

Because of its close relationship to bone, the obturator nerve is prone to injuries. Pelvic fractures and compression of the nerve during calving and foaling are the most common causes.

Sacral nerves (nn. sacrales)

The sacral nerves leave the sacral elements of the spinal cord by means of long dorsal and ventral roots. The roots merge to form the spinal sacral nerves within the sacral canal prior passing through the intervertebral foramina. In some individuals, the main trunks give off dorsal branches within the vertebral canal. In general, the branching pattern follows that of the lumbar spinal nerves. The dorsal branches are interconnected to form a small dorsal plexus. Like the dorsal branches of the lumbar spinal nerves, they divide into lateral branches that give off the dorsal cutaneous branches (nn. clunium medii) and medial muscular branches.

The **ventral branches of the cranial sacral nerves** form the **sacral plexus** (plexus sacralis), which joins with the ventral branches of the **last three lumbar spinal nerves** to form the **lumbosacral plexus.**

Lumbosacral plexus (plexus lumbosacralis)

The lumbosacral plexus is formed by the union of the:

- Lumbar plexus (plexus lumbalis),
- Sacral plexus (plexus sacralis).

The nerves that arise from the lumbar part of the plexus are described above. The sacral part of the plexus extends distally in the wall of the pelvic cavity as the sciatic plexus. It gives origin to the following nerves:

- Cranial gluteal nerve (n. glutaeus cranialis),
- Caudal gluteal nerve (n. glutaeus caudalis),
- Caudal femoral cutaneous nerve (n. cutaneus femoris caudalis),
- Pudendal nerve (n. pudendus) and
- Caudal rectal nerves (nn. rectales caudales).

The sciatic plexus continues as the sciatic nerve after the detachment of these branches.

Cranial gluteal nerve

The cranial gluteal nerve leaves the pelvis by passing immediately over the greater ischiatic notch, accompanied by the like-named blood vessels (Fig. 14-72 and 73). Its branches innervate the middle and deep gluteal muscles, the tensor fasciae latae and the piriform muscles.

Caudal gluteal nerve

The caudal gluteal nerve arises from the **caudal margin of the sciatic plexus** and passes caudally to innervate the biceps femoris and the gluteobiceps muscle (Fig. 14-72 and 73). Depending on the species, it also innervates the superficial gluteal muscles and the vertebral heads of the hamstring muscles.

Caudal femoral cutaneous nerve

The caudal femoral cutaneous nerve passes caudally towards the ischial tuberosity, where it detaches motor branches to the semitendinosus muscle (Fig. 14-73). It reaches a subcutaneous position and gives off an array of branches, the **caudal clunial nerves** (nn. clunium caudales), that innervate an extensive territory surrounding the ischial tuberosity and the caudal aspect of the thigh. It exchanges fibres with the puden-

Tab. 14-8. Summary of the areas of innervation of the lumbar plexus.

Nerve	Innervation motor	sensory
Lumbar nerves		
Iliohypogastric nerve	Abdominal muscles	Skin ventral in the abdominal region and medial of the femur
Ilioinguinal nerve	Abdominal muscles	Skin ventral in the abdominal region and medial of the femurl
Genitofemoral nerve	Internal oblique abdominal muscle Cremaster muscle	Scrotum, udder preputium, Skin medial of the femur
Lateral cutaneus nerve of the femur	Greater psoas muscle	Skin craniomedial of the femur and the knee joint
Femoral nerve	Inner lumbar muscles Quadriceps muscle	
Saphenous nerve	Sartorius muscle, partly Pectineal muscle, partly Gracilis muscle, partly	Skin medial of the knee joint and medial of the crural region
Obturator nerve	Pectineal muscle, partly Gracilis muscle, partly Adductor muscles External obturator muscle ox and pig Internal obturator muscle	

dal nerve. In ruminants, in which the caudal femoral cutaneous nerve is thin, much of the territory is covered by branches of the pudendal nerve.

Pudendal nerve

The pudendal nerve arises mainly from the ventral branch of the **third sacral spinal nerve** (Fig. 14-73). It sends communicating branches to the caudal femoral cutaneous nerve.

It innervates the copulatory organs and the muscles in the anal and perineal region. It provides sensory innervation to the skin around the anus, the perineal region and overlaps with the territory of the caudal clunial nerves. It is motor to the ischiocavernous, bulbospongious, retractor penis, urethral, constrictor vulvae, coccygeal, and levator ani muscles as well as the internal and external anal sphincter.

In the male, it continues as the dorsalis nerve of the penis to innervate the glans penis, where it arborizes. Its fine terminal branches carry sensory bodies. In the female, it terminates in the vulva.

The origin of the pudendal nerve conveys many **parasympathetic fibres,** which leave the main trunk in its proximal part to form the **pelvic nerves** (nn. pelvini). The pelvic nerves pass to the **pelvic plexus,** where they are joined by **sympathetic fibres** from the **hypogastric** and **sacral splanchnic nerves** to innervate the pelvic viscera. These fibres form organ specific plexuses, with parasympathetic axons synapsing in intramural ganglia (Fig. 14-82 and 85).

Caudal rectal nerves (nn. rectales caudales)

The caudal rectal nerves are the most **caudal branches of the sacral plexus** and may arise from the pudendal nerve (Fig. 14-73). They innervate the caudal rectum, the external anal sphincter and the skin surrounding the anus.

Sciatic nerve

The sciatic nerve is the **largest nerve in the body.** It is the continuation of the **sciatic plexus** within the pelvic limb. It leaves the pelvis through the greater sciatic foramen and passes over the lateral surface of the broad sacrotuberous ligament in large animals. It crosses the deep gluteal muscle and the hip joint to reach the caudal aspect of the femur (Fig. 14-73 and Table 14-11). Here it is susceptible to injuries following trauma and surgery of the hip joint.

The **sciatic nerve** provides **motor innervation** to the deep gluteal, the internal obturator, the quadriceps femoris and the gemelli muscles. It provides sensory fibres to the capsule of the hip joint. At the proximal third of the femur it terminates by dividing into the **tibial** and **common fibular (peroneal) nerves** (Fig. 14-75 to 79 and Table 14-11).

Tab. 14-9. Summary of the areas of innervation of the sacral plexus.

Nerve	Innervation motor	sensory
Cranial gluteal nerve	Middle gluteal muscle Piriform muscle Deep gluteal muscle Tensor of fascia lata	
Caudal gluteal nerve	Cranial part of the biceps muscle and of the femur (gluteobiceps muscle) Vertebral portion of the semitendinous muscle and the semimembranous muscle	
Caudal cutaneous nerve of the femur	Semitendinous muscle, partly	Skin of the hamstring region
Pudendal nerve	Ischiocavernous muscle Bulbocavernous muscle Urethral muscle Retractor muscle of penis and others	Skin, anus perineum clitoris, penis
Caudal rectal nerves	External anal sphincter muscle Coccygeal muscle Levator of anus	Skin of the anal region Caudal part of the rectum

Fig. 14-74. Nerves and blood vessels of the femoral canal and the medial aspect of the thigh of a cat (courtesy of Dr. R. Macher, Vienna).

Fig. 14-75. Superficial nerves of the leg of an ox, lateral aspect.

Fig. 14-76. Nerves of the thigh and leg of a dog, lateral aspect.

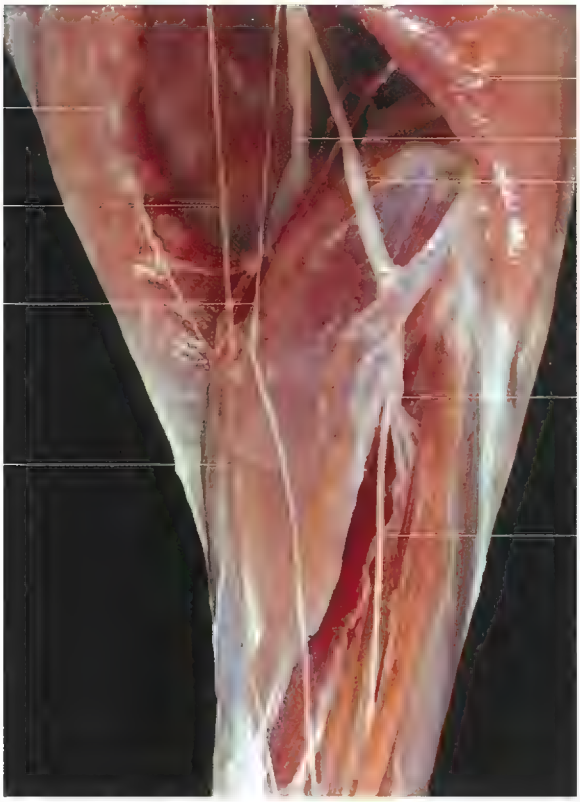


Abb. 14-77. Nerves of the right thigh and leg of a cat, lateral aspect (Langer, 1994).

Common fibular (peroneal) nerve

The common fibular nerve passes over the lateral head of the gastrocnemius to the proximal end of the fibula, where it becomes subfascial and is palpable under the skin. Before it divides into **superficial** and **deep branches,** it detaches the **lateral sural nerve** (n. cutaneus surae lateralis) to the skin on the lateral aspect of the stifle and proximal leg. The **superficial fibular nerve** runs distally along the lateral margin of the long digital extensor muscle and sends branches to the lateral digital extensor muscle. It innervates the skin on the dorsal aspect of the leg. On the flexor side of the tarsus it terminates by dividing into medial and lateral branches, that subdivide into the dorsal nerves of the digits (Fig. 14-73).

The **deep fibular nerve** runs deep between the muscles of the leg, accompanied by the cranial tibial artery. In the proximal third of the leg, it detaches branches to the flexor muscles of the tarsal and phalangeal joints (cranial tibial, long fibular, third fibular, short fibular, long digital extensor, lateral digital extensor and extensor hallucis longus muscles). Similar to the superficial branch it divides into **lateral** and **medial branches** on the dorsal aspect of the tarsus. The lateral branch detaches fibres to the short digital extensor tendon. The two branches of the deep fibular nerve join the corresponding branches of the superficial fibular nerve at the level of the proximal phalangeal joint to innervate the dorsal aspect of the digits (Fig 14-73 and 75 to 77).

Tibial nerve

The tibial nerve is the **stronger of the terminal branches** of the sciatic nerve. Shortly after separating from the common fibular nerve, the tibial nerve detaches the strong proximal muscular branches to the pelvic heads of the hamstring muscles (biceps femoris, semitendinous and semimembranous muscles) in the proximal third of the thigh (Fig. 14-72, 76 and 77).

In the midfemoral region it gives off the **caudal sural nerve** (n. cutaneus surae caudalis), that passes caudally, together with the lateral saphenous vein, to reach a subcutaneous position along the caudal aspect of the crus. At the caudal aspect of the stifle, it passes deep between the two heads of the gastrocnemius muscle. At this level, it detaches the distal muscular branches to the gastrocnemius, the deep digital flexor, the superficial digital flexor and the popliteal muscles. It continues to the medial side of the tarsus between the common calcanean tendon and the heads of the deep digital flexor muscle, where it is palpable in large animals.

When level with the calcaneus, the tibial nerve divides into the **medial** and **lateral plantar nerves** (Fig. 14-78 and 79). At the level of the proximal phalanx, they divide again into **lateral** and **medial plantar digital nerves,** which resemble those of the forelimb.

Damage to the sciatic nerve or its terminal branches may be caused by fractures of the femoral neck, by misdirected intramuscular injections or as complication of hip surgery.

Tab. 14-10. Summary of the areas of innervation of the sciatic nerve.

Nerve	Innervation motor	sensory
Sciatic nerve	Gemelli muscles Deep gluteal muscle Internal obturator muscle Quadriceps muscle of thigh	
– Tibial nerve	All muscles lying caudal of the femur and on the tibia and fibula: Pelvic heads of the biceps femoris muscle Semitendinous muscle Semimembranous muscle Gastrocnemius muscle Soleus muscle Popliteal muscle Superficial digital flexor muscle Deep digital flexor muscle	
– Caudal sural nerve		Skin of the caudal aspect of crus
– Plantar nerves	Interosseous muscles	Skin of the autopodium
Common fibular nerve – Lateral cutaneous of the lower limb		Skin lateral of the knee joint
– Superficial fibular nerve	Lateral digital extensor muscle	Skin dorsolateral on the lower limb and the digit
– Deep fibular nerve	All the muscles lying craniolateral on the lower limb: Cranial tibial muscle Long digital extensor muscle Lateral digital extensor muscle Long fibular muscle Short fibular muscle Third fibular muscle Short digital extensor muscle	

Comment: The nerves of the lumbosacral plexus contain motor, sensory as well as vegetative fibres.

Depending on the level of injury it is usually manifested by a non-weightbearing lameness, this will result in rapid atrophy of the deprived muscles, and considerably sensory deficits.

Tab. 14-11. Innervation of the joints of the hindlimb.

Joints	Nerves
Hip joint	Sciatic nerves
Knee joint	Tibial nerve and saphenous nerve
Hock	Tibial nerve Superficial and deep fibular nerve
Digital joints	Plantar nerves of the tibial nerve, digital nerves

Peripheral autonomic nervous system (systema nervosum autonomicum)

The **autonomic** (also called **visceral** or **vegetative**) nervous system forms the **idiotropic part** of the peripheral nervous system and is closely linked to the central nervous system by cranial and spinal nerves. It is composed of a multitude of small nerves, plexus and ganglia, co-ordinates the function of the internal organs essential for life. It regulates respiration, circulation, digestion, metabolism, body temperature, water balance, reproduction and many other body functions. Most of the mechanisms, that fulfil these functions also occur in the unconscious animal, e.g. during sleep or under general anaesthesia, hence the term "autonomic". However, it is still regulated by cerebrospinal mechanisms. For example optic stimuli and aggressive or depressive emotions influence respiration, cardiac activity and gastrointestinal function.

The autonomic nervous system is concerned with the motor innervation of smooth muscles of the internal organs and blood vessels, as well as the regulation of the endocrine and

Fig. 14-78. Nerves of the left hindfoot of the horse, lateral aspect.

exocrine function of glands. There is a close interaction between the nervous system, the endocrine system and the immune system. (For more details see neurophysiology and immunology textbooks.)

Structure of the autonomic nervous system

On anatomical, pharmacological and physiologic bases, the afferent component of the autonomic nervous system can be divided into **sympathetic** and **parasympathetic portions.** Both systems consist of pairs of neurons that link the central nervous system to the innervated structure.

The first multipolar neuron of each pair has its cell body within the central nervous system and sends its axon out as part of the peripheral system. This myelinated, **preganglionic neuron** synapses with the second neuron of the chain and the non-myelinated axon of the postganglionic neuron terminates on the cells of the effector organ (Fig. 14-80). The cell bodies of the preganglionic neurons of the sympathetic division are located within the lateral column of the thoracic and lumbar spinal cord. Those of the parasympathetic division are located in the nuclei of origin of certain cranial nerves within the brain stem and the lateral columns of sacral segments of the spinal cord.

The **postganglionic neurons** ordinarily occur in clusters referred to as ganglia. The sympathetic postganglionic neurons are located in vertebral ganglia of the sympathetic trunk or in more peripheral prevertebral ganglia. The parasympathetic postganglionic neurons are found within small ganglia in close proximity to, or within the walls of the organ they innervate.

The two systems can be distinguished on the base of their **transmitter substance.** The transmitter at the last sympathetic synapse is **noradrenaline,** while that of the **parasympathetic portion** is **acetylcholine.** Both divisions have a similar distribution and have stimulating or inhibiting influences on an organ depending on the overall activity of these systems. It is generally true that sympathetic stimulation results in an overall increase in body activity, while parasympathetic stimulation has a sparing effect on the body.

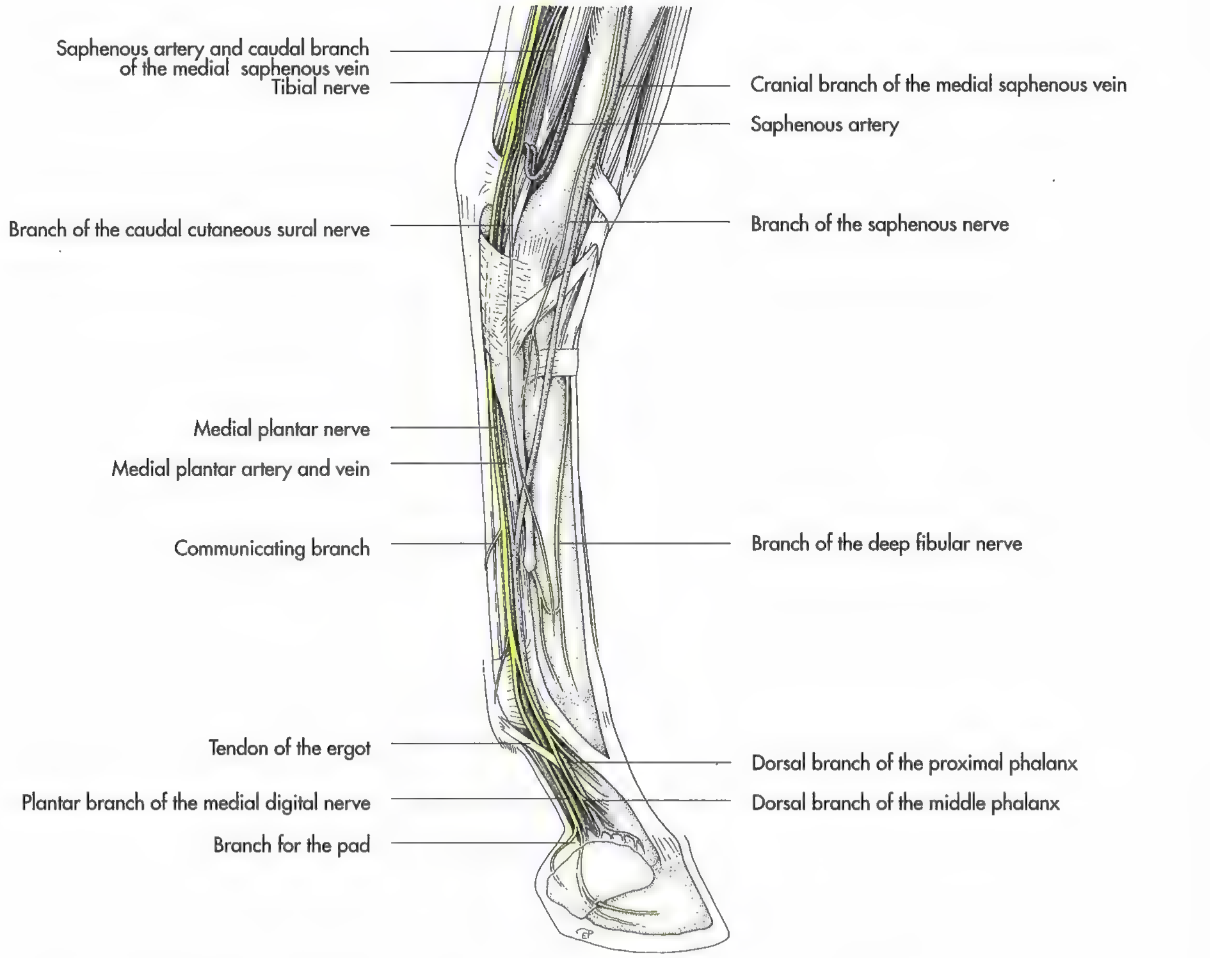


Fig. 14-79. Nerves of the left hindfoot of the horse, medial aspect.

Sympathetic system

The cell bodies of the **preganglionic neurons** of the sympathetic system are located in the lateral column of the spinal cord between the first thoracal and the third lumbar segments. Their axons join the ventral roots to reach the spinal nerves from which they pass, to the vertebral ganglia of the sympathetic trunk as the **white communicating branches** (nn. communicantes albi) (Fig. 14-80). After entering the sympathetic trunk there are several courses that preganglionic fibres follow: some fibres synapse immediately within the local ganglion, others run cranially or caudally within the trunk to synapse in other vertebral ganglia. The majority passes uninterrupted through the trunk to synapse in prevertebral ganglia located at the origins of the visceral branches of the abdominal aorta. This last group constitutes the **splanchnic nerves.**

Sympathetic trunk (truncus symphaticus)

The sympathetic trunk consists of two chains of vertebral ganglia that have a segmental arrangement and are interconnected both longitudinally and transversely. It can be divided into several parts:

- Cephalic and cervical part (pars cephalica et cervicalis),
- Thoracic part (pars thoracica),
- Abdominal part (pars abdominalis) and
- Sacral and coccygeal part (pars sacralis et coccygea).

Cephalic and cervical part of the sympathetic trunk

The cephalic and cranial part of the sympathetic trunk is the cranial continuation of the thoracic part, without directly contacting the vertebral column. In the cervical region each chain runs in a common sheath with the vagus nerve, forming the **vagosympathetic trunk** (truncus vagosympathicus), dorsal to the common carotid artery (Fig. 14-81 to 84).

The cervical part starts at the **cervicothoracic ganglion** (stellate ganglion, ganglion cervicothoracicum seu stellatum), which is connected to the **middle cervical ganglion** (ganglion cervicale medium) cranioventral to it via the ansa

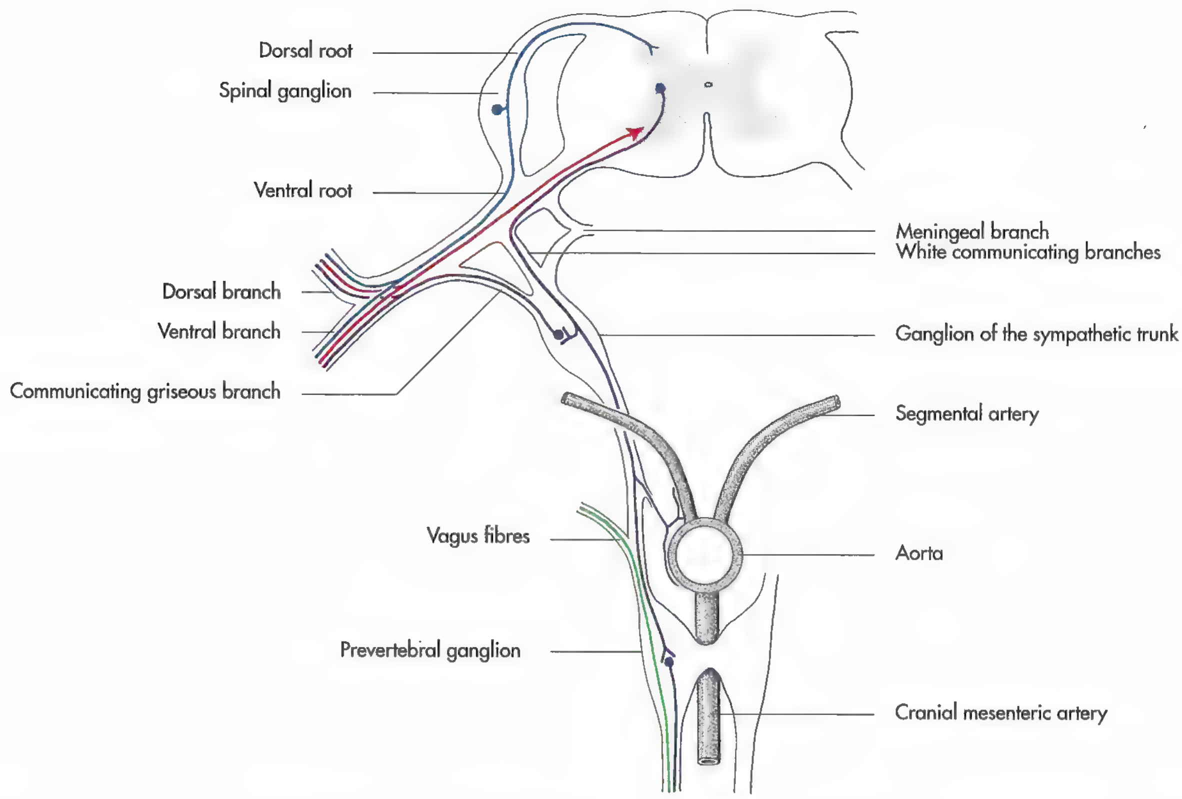


Fig. 14-80. Schematic illustration of the visceral part of the autonomic nervous system (red = motor, blue = sensory, lilac = pre- and postganglionic sympathetic fibres, green = parasympathetic fibres of the vagal nerve) (Ellenberger and Baum, 1943).

subclavia. The cervical part passes cranially from the middle cervical ganglion to combine with the vagus nerve in a common sheath (Fig 14-81 and 83). At the atlas, the sympathetic part separates from the vagus to then terminate in the large **cranial cervical ganglion** (ganglion cervicale craniale).

In the horse, it runs along the internal carotid artery in a caudal fold in the medial compartment of the guttural pouch. The **cranial cervical ganglion** provides sympathetic innervation for the head. Postganglionic fibres from the cranial cervical ganglion join the ninth, tenth, eleventh and twelfth cranial nerves and extend to the adventitia of all cranial arteries. Only postganglionic fibres leave the ganglion.

The **internal carotid nerve** (n. caroticus internus) arises from the apex of the cranial cervical ganglion, and is directed towards the brain and passes to the lacerated foramen with the internal carotid artery. It innervates the blood vessels within the cranial cavity and detaches fibres, which combine with the trigeminal and other cranial nerves.

The **middle cervical ganglion** is connected to the cervicothoracic ganglion by the ansa subclavia, which divides to pass around the subclavian artery. Most of its neurons innervate the cardiac plexus.

The **cervicothoracic ganglion** lies medial to the first rib. It marks the end of the cervical sympathetic trunk and the start of the thoracic part of the sympathetic trunk. As indicated by its name it is formed by the fusion of the caudal cervical ganglion with one or more thoracic ganglia.

The following branches arise from the cervicothoracic ganglion:

- Communicating branches (rami communicantes) to the first two thoracic nerves,
- Vertebral nerve (n. vertebralis), that accompanies
- the like-named vessels through the transverse canal and provides the cervical spinal nerves with sympathetic fibres,
- Cervical cardiac nerves (nn. cardiaci cervicales), that innervate the cardiac plexus,
- Perivascular branches that accompanies the subclavian artery and
- Thoracic part of the sympathetic trunk as its caudodorsal continuation.

Thoracic part of the sympathetic trunk

The thoracic part of the sympathetic trunk shows a segmental arrangement of ganglia, the number of which roughly correspond to the number of thoracic vertebrae. Cranial thoracic

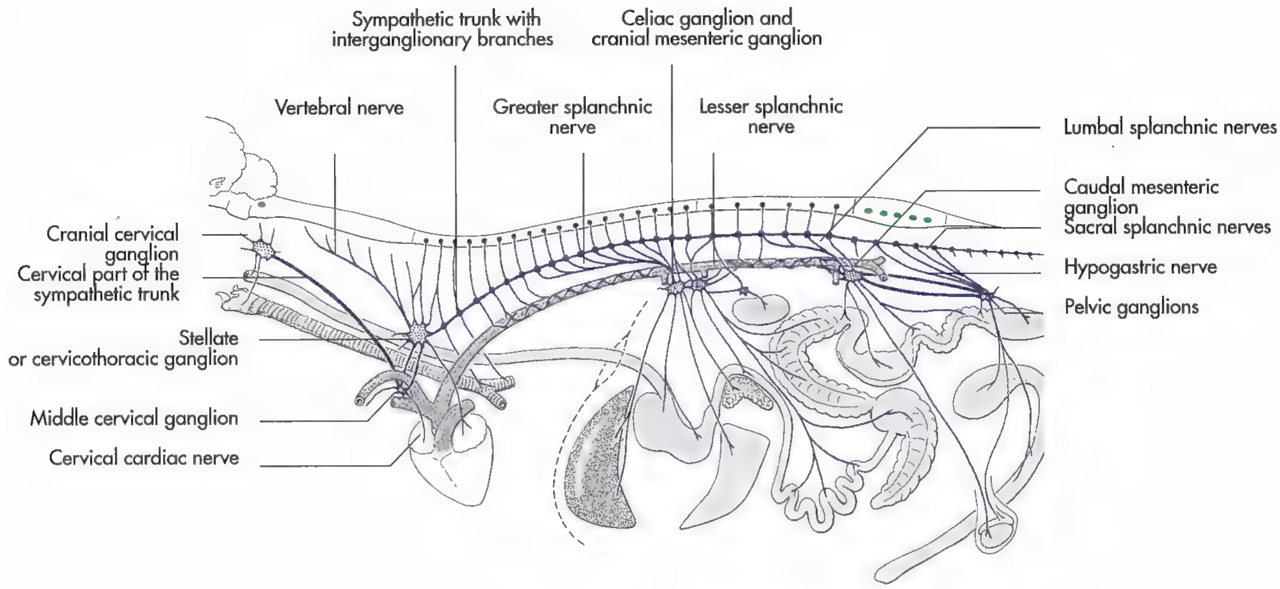


Fig. 14-81. Schematic illustration of the sympathetic nerves and ganglia of the horse.

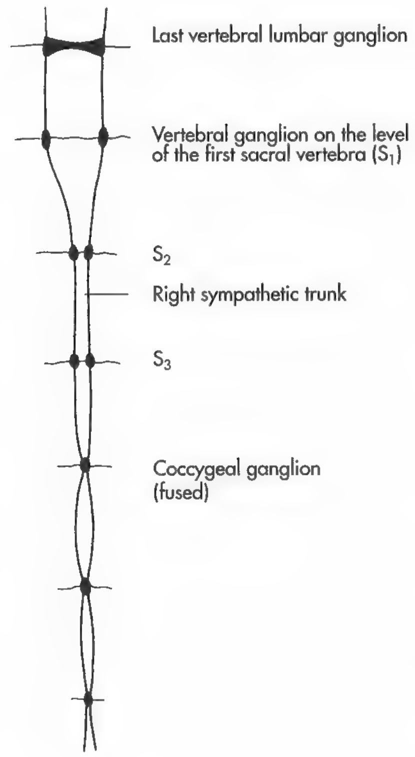


Fig. 14-82. Schematic illustration of the sacral and coccygeal part of the sympathetic trunk of the cat (Corpancho, 1986).

ganglia fuse with caudal cervical ganglia to form the **cervicothoracic ganglion.** Branches to the cardiac, esophageal and tracheal plexuses arise from the cranial thoracic ganglia (Fig. 14-81). From the sixth thoracic ganglion caudally, preganglionic neurons pass through the ganglia to reach the **greater splanchnic nerve** (n. splanchnicus major). The greater splanchnic nerve increases in diameter more caudally and enters the abdomen along the main sympathetic trunk between the crus of the diaphragm and the psoas minor muscle.

The **lesser splanchnic nerve** (n. splanchnicus minor) leaves the main sympathetic trunk caudal to the greater splanchnic nerve at the level of the last two or three caudal thoracic vertebra. It continues into the abdominal cavity with the greater splanchnic nerve and the main sympathetic trunk. Both splanchnic nerves pass with the celiac and the cranial mesenteric artery to the paired celiac and cranial mesenteric ganglion, which may be fused (Fig. 14-81).

Abdominal part of the sympathetic trunk

The abdominal part of the sympathetic trunk lies between the psoas musculature and the vertebral bodies. Lumbar splanchnic nerves (nn. splanchnici lumbales) pass from the lumbar ganglia to the celiac and cranial mesenteric ganglia (Fig. 14-81). Fibres of the autonomic nervous system form a dense plexus around the **prevertebral ganglia** and the roots of the celiac and cranial mesenteric arteries, called the **solar plexus** (plexus solaris).

This is continuous with the plexuses, which are distributed with the branches of the two arteries and are named after the organs they innervate: e.g. **enteric plexus** and **hepatic plexus.** A large, unpaired, prevertebral sympathetic ganglion is found at the caudal mesenteric root.

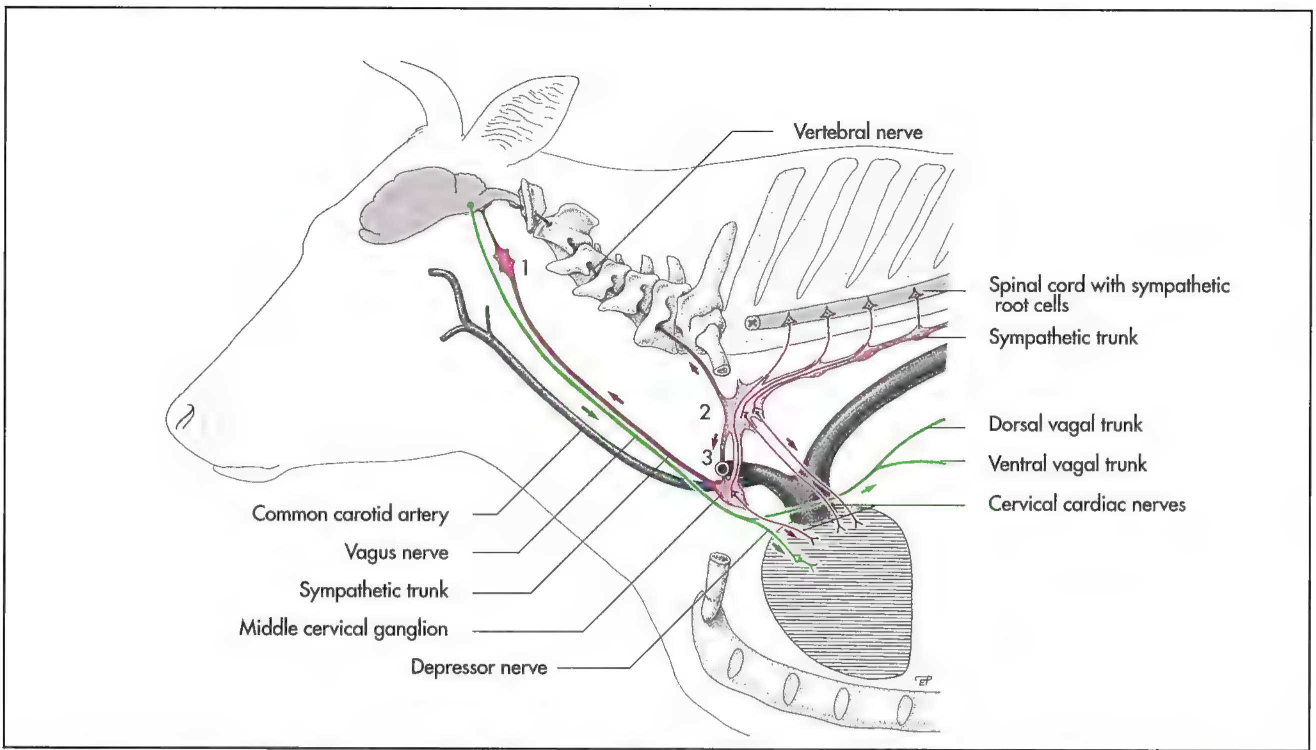


Fig. 14-83. Schematic illustration of the sympathetic and parasympathetic nerves in the cervical and thoracic region of the ox (1 = cranial cervical ganglion, 2 = cervicothoracic ganglion, 3 = ansa subclavia).

The **prevertebral ganglia** are connected with each other by the splanchnic nerves, the sympathetic trunk, and the abdominal aortic plexus at the aorta. The nervous plexus surrounding the prevertebral ganglia receive parasympathetic fibres from the vagus nerve.

Sacral and coccygeal part of the sympathetic trunk

The sacral part of the sympathetic trunk is less consistent between individuals and may partly fuse with the coccygeal part before extending into the tail, where it rapidly tapers. **Pelvic splanchnic nerves** (nn. splanchnici pelvini) pass from the sacral ganglia to the retroperitoneal **pelvic plexus.**

The pelvic plexus receives the **hypogastric nerves** (nn. hypogastrici), two nerve bundles, which pass from the caudal mesenteric ganglion into the pelvic cavity in a retroperitoneal position. The pelvic plexus receives parasympathetic fibres from the pelvic nerves (nn. pelvini) (Fig. 14-83).

Parasympathetic system

The cell bodies of the preganglionic neurons of the parasympathetic system are located in the nuclei of origin of certain cranial nerves in the brainstem and in the sacral spinal cord. Because of the brain stem and sacral spinal cord, the origin of parasympathetic fibres "craniosacral" is used as a synonym for parasympathetic. The parasympathetic nuclei of the cranial nerves are the (Fig. 14-84):

- Parasympathetic nucleus of the oculomotor nerve,
- Parasympathetic nucleus of the facial nerve,
- Parasympathetic nucleus of the glossopharyngeal nerve,
- Parasympathetic nucleus of the vagus nerve.

The **preganglionic axons** leave the brainstem as **part of these cranial nerves.** The axons in nerves III, VII and IX are distributed to the head, whereas the vagus nerve distributes autonomic fibres to the cervical, thoracic and abdominal viscera. Preganglionic parasympathetic fibres also leave the spinal cord as part of the ventral roots of the sacral nerves and become part of the pelvic plexus.

The preganglionic parasympathetic fibres of the **oculomotor nerve synapse** in the **ciliary ganglion** (ganglion ciliare). The postganglionic fibres innervate the ciliary muscle, which regulates lens curvature and the pupillary diameter. The parasympathetic preganglionic fibres of the **facial nerve** run with the chorda tympani to the lingual nerve and with the major petrosal nerve to the maxillary nerve. They synapse at the **mandibular** and the **pterygopalatine ganglia.** Postganglionic fibres of the mandibular ganglion innervate the sublingual and submandibular salivary glands; those of the **pterygopalatine ganglion** innervate the lacrimal, nasal and the palatine glands.

The preganglionic portion of the **glossopharyngeal nerve** joins the minor pterygopalatine nerve to synapse in the **otic ganglion,** near the origin of the mandibular branch of the tri-

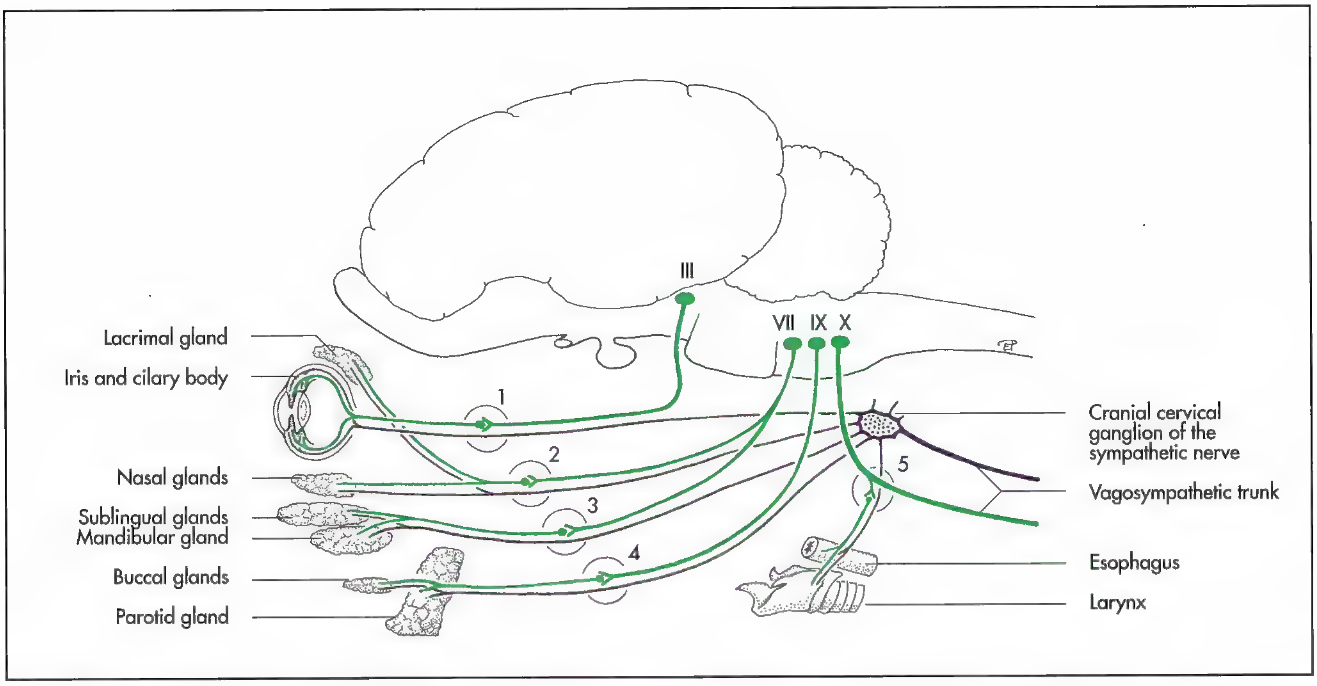


Fig. 14-84. Schematic illustration of the sympathetic (lilac) and parasympathetic (green) nerves of the head: 1 = ciliar ganglion, 2 = pterygopalatine ganglion, 3 = mandibular ganglion, 4 = otic ganglion, 5 = distal ganglion of the vagus nerve. Parasympathetic nuclei of cranial nerves III = oculomotor nerve, VII = intermediofacial nerve, IX = glossopharyngeal nerve, X = vagus nerve (Dyce, Sack and Wensing 1991).

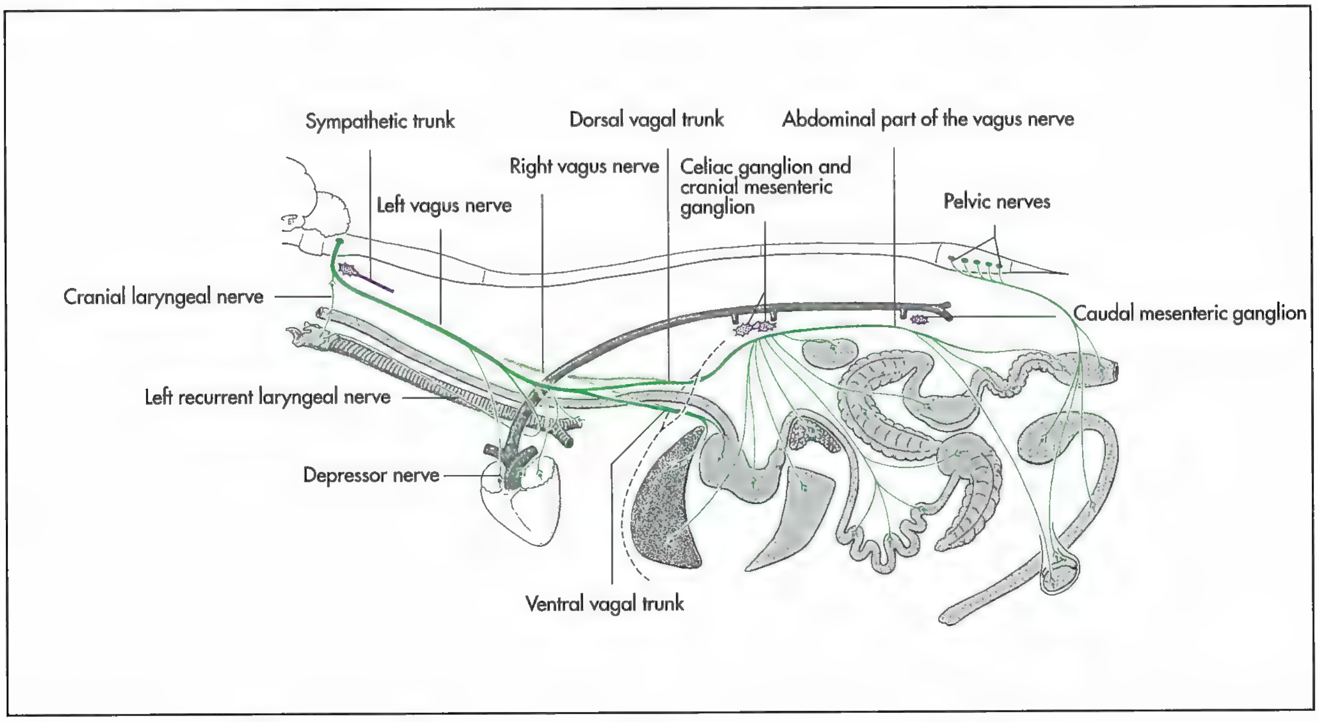


Fig. 14-85. Schematic illustration of the parasympathetic nerves of the neck, thorax, abdomen and pelvis.

geminal nerve. Postganglionic fibres innervate the buccal glands and the parotid gland. The axons of the largest parasympathetic nucleus leave the brain with the **vagus nerve,** with which they are distributed, to the organs of the thoracic and abdominal cavity. Synapses occur in ganglia along the nerve plexus, which they innervate and are often located within

the supplied organ (Fig. 14-85). The cell bodies of the preganglionic neurons of the sacral part of the parasympathetic system are located in the lateral column of the sacral spinal cord. Their axons leave the spinal cord with the sacral nerves and form the **pelvic nerves,** which join sympathetic fibres in the pelvic plexus. They form organ specific plexuses from which the pelvic viscera are supplied.

Intramural system

The intramural system includes the plexus and ganglia that are located within the tissues of organs. It ensures independent function of the viscera with central control e.g. peristalsis of the intestine continues after the supplying vegetative nerves have been sectioned. In hollow organs the intramural system consists of nerve plexus at three different levels:

- Subserosal nerve plexus,
- Myenteric nerve plexus,
- Submucosal nerve plexus.

Clinical terms related to the nervous system:
Neuritis, encephalitis, meningitis, meningoencephalitis, neuroma, radiculitis, neuralgia.

15 Endocrine glands (glandulae endocrinae)

H. E. König and H.-G. Liebich

Endocrine glands are ductless glands that produce substances, termed hormones, which are released into the circulatory system and transported to distant receptor organs. Some hormones diffuse directly to their target cells via the interstitial fluid (e.g. the gastroenteropancreatic system). Most endocrine glands release their hormones into post-capillary veins that do not drain into the portal vein, but circulate around the whole organism before reaching the liver.

Hormones bind to **specific receptors** found in their target sites, to either enhance or suppress the activity of the target organs, tissues or cells. Endocrine organs supplement and augment the function of the autonomic nervous system, and both are collectively described as the "neurohormonal system".

Hormones are produced by **parenchymal cells,** that are found **singly** (e.g. in the epithelium of the gastrointestinal tract, in the wall of bronchi and the urethra, in the kidneys and in the myocardium), as **aggregates** (e.g. the Langerhans´ cells in the pancreas, Leydig´s-cells in the testes and corpus luteum) or are organised in **endocrine organs** (pituitary gland, thyroid gland, pineal gland, adrenal gland). Some organs have both exocrine and endocrine functions (testis, ovary, pancreas, placenta) and some have an endocrine function, that is secondary to their principle function (kidney, liver, thymus).

The function of the endocrine tissues is regulated by simple or complex feedback mechanisms, many of which involve the pituitary gland.

The pituitary gland (hypophysis seu glandula pituitaria)

The pituitary gland plays a **major regulatory role** in the entire endocrine system. It is sometimes referred to as the "master gland" of the body. It is a small **unpaired organ,** that is suspended below the diencephalon in the hypophyseal fossa of the sphenoid bone between the optic chiasm and the mamillary body. The hypophyseal fossa is bound by the tuberculum sellae rostrally and the dorsum sellae caudally. The dura mater forms the diaphragma sellae around the hypophyseal stalk and contains prominent **cavernous sinuses.** The pituitary gland consists of **two parts,** which are derived from different embryological origins and have separate functions: the **neurohypophysis** and the **adenohypophysis** (Fig. 15-1 to 4).

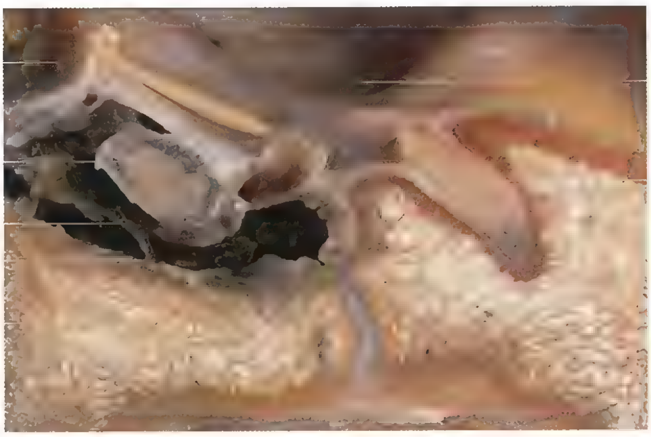


Fig. 15-1. Pituitary gland of a horse and adjacent structures, paramedian section (courtesy of PD Dr. J. Maierl, Munich).

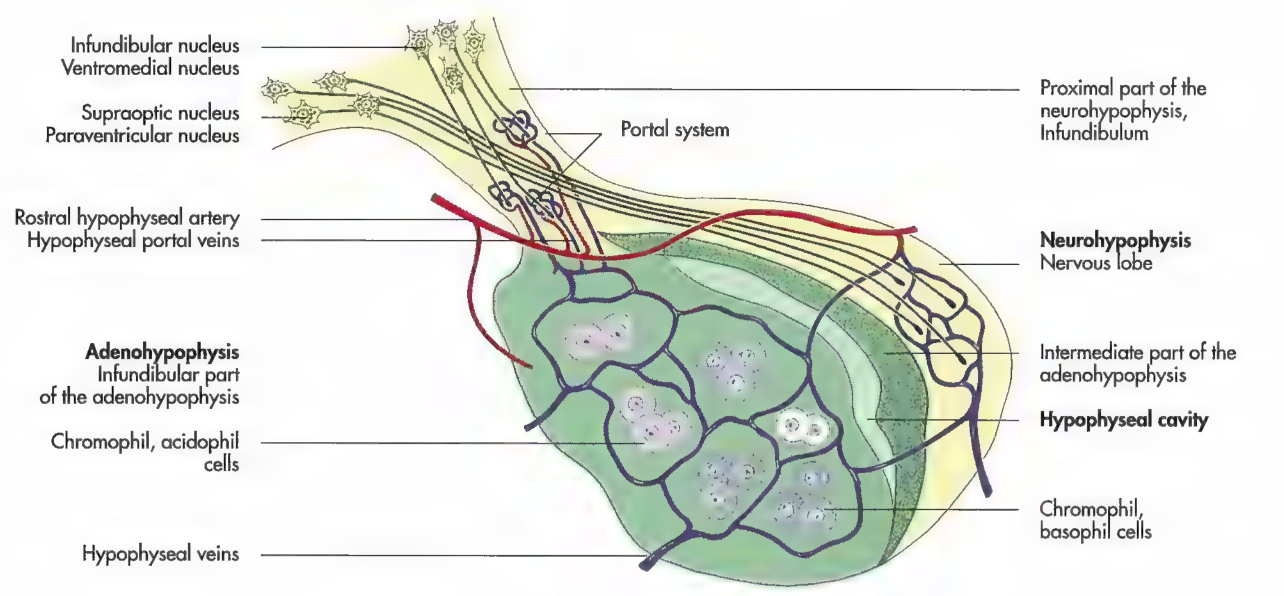


Fig. 15-2. Schematic illustration of the hypothalamus-hypophysis system (Liebich, 2004).

The **neurohypophysis** is located caudal to the adenohypophysis and is a neural outgrowth of the **hypothalamus.** It consists of the stalk, that connects the pituitary gland to the **tuber cinereum** of the hypothalamus (infundibulum seu pars proximalis) and the distal, major portion of the neurohypophysis (pars distalis). The third ventricle extends into the neurohypophysis through the cylindrical stalk as the neurohypophyseal recess. The neurohypophysis stores and releases hormones, that are produced by the neurosecretory cells of the **supraoptic** and **paraventricular nuclei** of the hypothalamus. These hormones, oxytocin, vasopressin and anti-diuretic hormone (ADH), are conveyed along axons and released into the neurohypophyseal capillary bed.

The **adenohypophysis** from the epithelium of the dorsal pharyngeal roof and becomes the **anterior lobe of the pituitary gland.** Most of the adenohypophysis lies distal to the neurohypophysis and continues onto the stalk as **infundibular part of the adenohypophysis** (pars infundibularis). The portion of the adenohypophysis in direct contact with the distal part of the neurohypophysis is termed the **intermediate lobe** (pars intermedia adenohypophysis) owing to its location between the two major parts of the pituitary gland.

In the cat, dog and horse the intermediate lobe extends around the neurohypophysis. The anterior lobe is separated from the intermediate lobe by the **hypophyseal cleft** (cavum hypophysis), a remnant of development that is not present in the horse.

The hypophysis has its **own portal system,** that is responsible for the **transportation of hormones** (releasing and inhibiting factors) from nuclei in the hypothalamus to the adenohypophysis. The **anterior lobe** of the adenohypophysis produces several hormones: growth hormone (GH), gonadotrophic hormones (follicle stimulating and luteinizing hormones), adrenocorticotrophic hormone (ACTH), thyroid-stimulating hormone (TSH) and prolactin. The **intermediate lobe** produces melanocyte-stimulating hormone and several other hormones.

Because of the close anatomical and functional relationship between the hypothalamus and hypophysis, the two are collectively described as the hypothalamic-pituitary axis.

Secondary pituitary glands may develop within the dura mater between the pituitary gland and the pharynx, especially in cats and ruminants.

Pineal gland (epiphysis cerebri seu corpus pineale, glandula pinealis)

The pineal gland is part of the **diencephalon.** It is an unpaired organ, located in the epithalamus and structurally resembles a pine cone. The size of the pineal gland varies greatly among the species and between individuals. It is connected to the roof of the diencephalon by the habenulae and the short peduncle.

The pineal gland is innervated by **postganlionic sympathetic fibres** from the **cranial cervical ganglion** that extend to the organ within the adventitia of small blood vessels. The endocrine cells of the pineal gland produce melatonin, serotonin and other peptide hormones. The activity of these cells is influenced by a chain of neurons that pass from the retina, via the hypothalamus, thoracic spinal cord and the cranial cervical ganglia to the pineal gland. Melatonin has gonadotrophic effects, which are important in seasonality of reproductive cycles in certain species, such as the horse and sheep. As such, the pineal gland functions as **"biological clock",** regulating seasonal and diurnal variation in gonadal activity. In the horse, where melatonin has anti-gonadotrophic effects, melatonin production is inhibited by light stimuli, so that as

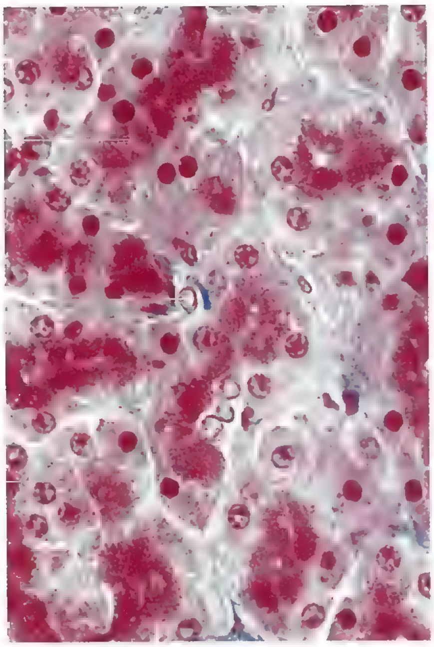


Fig. 15-3. Histological section of the adenohypophysis of an ox.

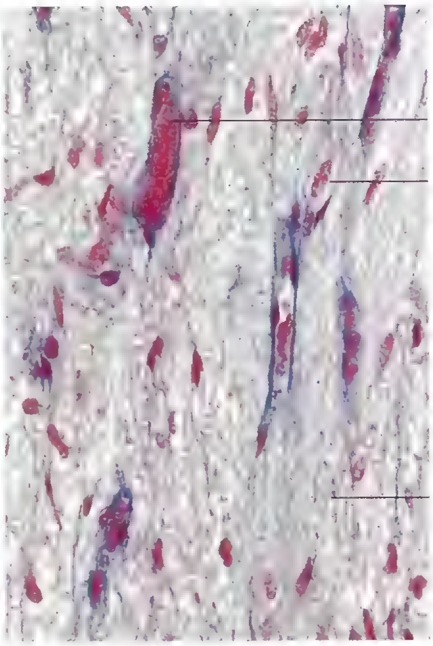


Fig. 15-4. Histological section of the neurohypophysis of an ox.

day-length increases in the spring, melatonin production decreases and its inhibitory effect on gonad activity reduces (long-day breeding).

In sheep, melatonin is also suppressed by daylight, so that as night-length increases, melatonin release increases. However, in sheep, melatonin enhances gonadotrophic function, so that breeding occurs in the autumn. This is of clinical importance, since administration of melatonin in sheep can be used to advance the breeding period.

Thyroid gland (glandula thyroidea)

The hormones produced by the thyroid gland control metabolic rate, growth, body temperature, carbohydrate metabolism and blood calcium levels. Secretory activity of the thyroid gland is regulated by thyreotropin (TSH), a hormone of the adenohypophysis.

Thyroxine (T3) and tetra-iodothyronine (T4) are produced by **follicular cells,** and are stored in follicular fluid prior to their release into the blood stream. The iodine content of the diet is essential to the production of thyroid hormones, so that iodine deficiency may cause enlargement of the thyroid gland (goitre). **Hyperthyroidism** leads to an increase in metabolism and the animals appear restless and nervous, sometimes even aggressive. Hypothyroidism causes the organism to slow down metabolism, growth and activity. Congenital hypothyroidism results in stunted growth and mental retardation.

Parafollicular, or C-cells produce calcitonin, a hormone that lowers blood calcium concentrations and thus acts as an antagonist to the parathyroid hormone.

Position and form of the thyroid gland

The thyroid gland is located to either side, **ventral to the trachea** at its most cranial part, sometimes overlapping the larynx. In all domestic mammals, other than the pig, it consists of **left** and **right lobes,** that are connected caudally by a connective tissue strand **(isthmus)** extending on the ventral side of the trachea (Fig. 15-5 to 8, 10 and 11).

In the cat, the flat, **spindle-shaped lobes** lay on the dorsolateral aspect of the trachea extending over the first seven to ten tracheal rings. Their caudal poles are connected by a thin isthmus of about 1–2mm.

In the dog, the thyroid gland consists of two **elongated, oval lobes** on the dorsolateral aspect of the trachea that extend from the fifth to the eighth tracheal ring. The isthmus is often formed of glandular parenchyma, especially in large breed dogs (Fig. 15-5).

Unlike in the other domestic mammals the thyroid gland of the pig is an **unpaired, compact organ** on the ventral aspect of the trachea. Its cranial pole lies at the thyroid cartilage, while the pointed caudal end reaches the thoracic inlet. Its surface has a granular appearance.

In the ox the **two lobes** are irregularly shaped with a granular appearance, that roughly resembles pyramids. They are situated dorsally on the lateral side of the cricopharyngeal and the cricothyroid muscles (Fig. 15-7). The lobes are connected by a substantial isthmus that crosses the ventral aspect of the second tracheal ring.

In small ruminants the **spindle to cylindrical shaped lobes** lay on the dorsolateral aspect of the cranial tracheal rings. The isthmus is not present in all animals.

In the horse the lobes of the thyroid are **oval-shaped** and about the size of a plumb. They are situated dorsolateral to

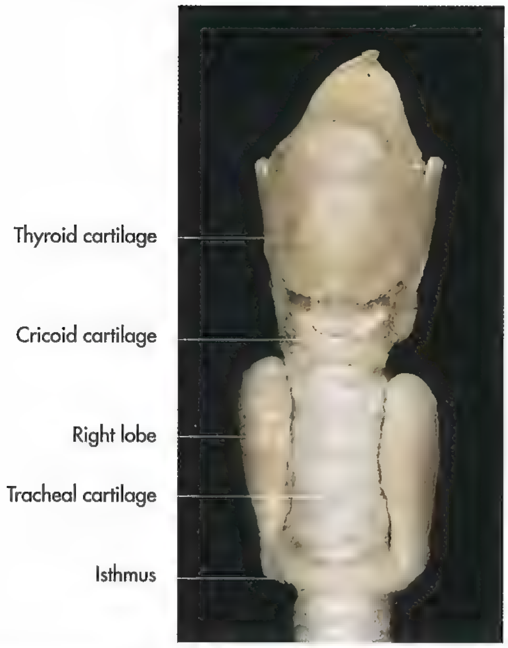


Fig. 15-5. Thyroid gland of a dog, with trachea and larynx, ventral aspect.

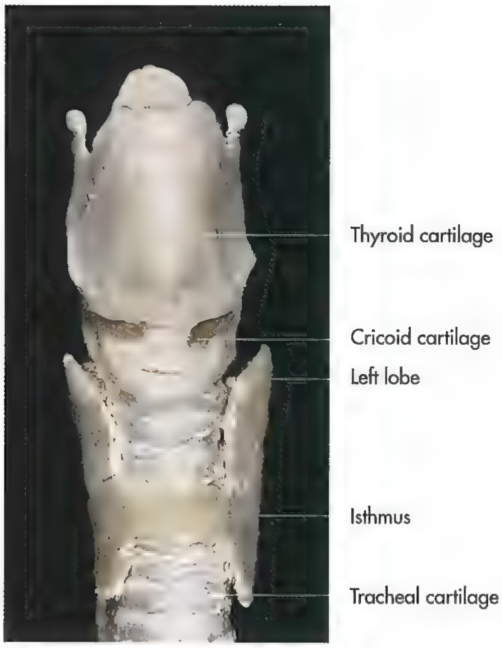


Fig. 15-6. Thyroid gland of a goat, with trachea and larynx, ventral aspect.

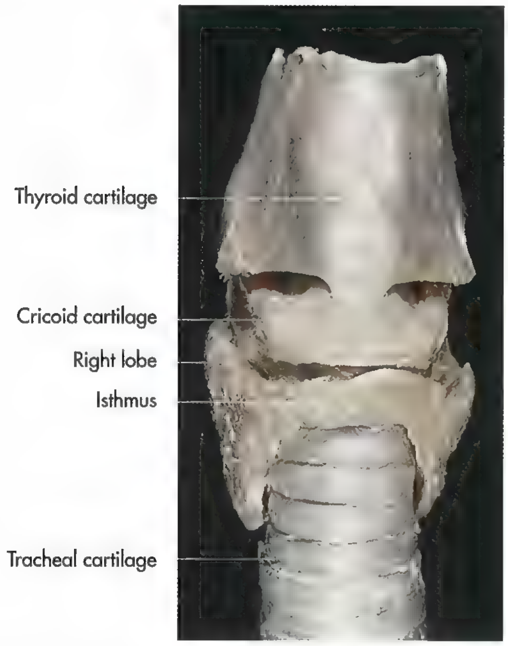


Fig. 15-7. Thyroid gland of an ox, with trachea and larynx, ventral aspect.

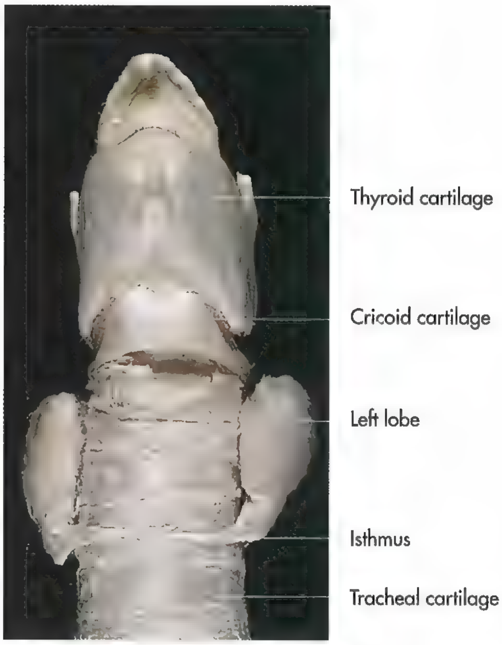


Fig. 15-8. Thyroid gland of a horse, with trachea and larynx, ventral aspect.

the second and third tracheal ring and are joined ventrally by a **narrow strand** of connective tissue (Fig. 15-8 and 12).

Accessory thyroid glands are usually located close to the main organ. However, they may also be found around the hyoid apparatus, along the whole of the trachea, in the mediastinum and in the lingual mucosa of the cat.

Blood supply, lymphatic drainage and innervation of the thyroid gland

Blood supply of the thyroid gland is provided by branches of the **common carotid artery.** The main branch is the cranial thyroid artery that branches to parts of the larynx. Addition vascular supply is provided by the caudal thyroid artery, which is frequently absent in the ox and goat, but contributes

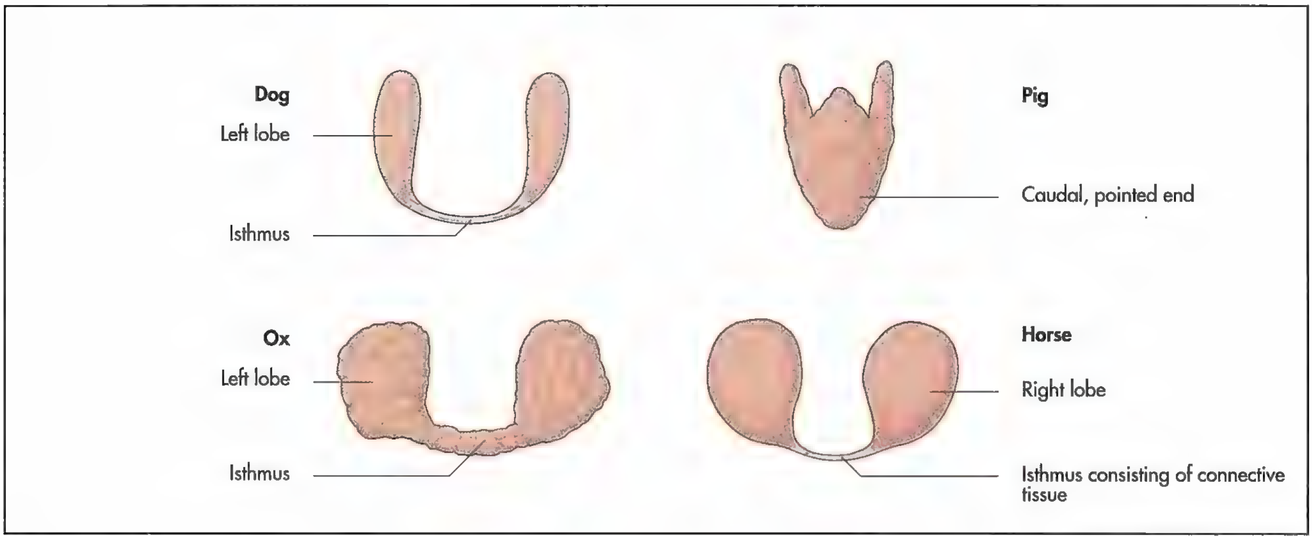


Fig. 15-9. Schematic illustration of the thyroid gland of the different domestic species (Ghetie, 1967).

the main supply in the pig. Variations regarding the origin and course of the thyroid vessels are common.

Venous drainage is achieved by the cranial and middle thyroid veins that drain into the internal jugular vein in all domestic mammals other than the horse, where no internal jugular vein is present. In the horse they drain into the **external jugular vein.** In the dog and cat, the cranial thyroid veins are connected by the caudal laryngeal arch in which the unpaired, **median caudal thyroid vein opens.** The thyroid veins also vary greatly between species and individuals.

Lymphatic drainage of the thyroid gland is to the deep cervical lymph nodes or directly to the tracheal trunk.

The thyroid gland is innervated by both the **sympathetic** and **parasympathetic nervous systems.** Sympathetic fibres originate in the cranial cervical ganglion, while parasympathetic fibres supply the organ from branches of the caudal and cranial laryngeal nerves, both of which are branches of the vagus nerve.

Parathyroid glands (glandulae parathyroideae)

The parathyroid glands are **bilaterally paired** small epithelial structures that are located both embedded within the thyroid gland and also close to its capsule.

They develop from the epithelium of the **third** and **fourth pharyngeal pouches.** The **internal parathyroid glands** are also named parathyroid IV, indicating their origin and the external glands are named parathyroid III, respectively.

The parathyroid glands produce parathyroid hormone, which regulates serum concentrations of calcium and phosphorus by regulating metabolism within bone, absorption from the gastro-intestinal tract and excretion in the urine.

Incidental extirpation of all parathyroid glands during bilateral thyroidectomy in cats results in severe hypocalcaemia, which can be fatal. Tetany due to lack of calcium, necessary for proper muscular function preceedes death.

Species specific variations

Cat:
- Internal parathyroids are located within the thyroid parenchyma, close to the medial surface of each lobe,
- External parathyroids are found close to the cranial pole of the thyroid gland.

Dog:
- Internal parathyroids are embedded within the middle portion of each lobe.
- External parathyroids are found close to the cranial pole or the cranial half of the thyroid gland.

Pig:
- Internal parathyroids are not present.
- External parathyroids are pea-like structures at the bifurcation of the common carotid artery.

Small ruminants:
- Internal parathyroids are found at the cranial pole of each lobe.
- External parathyroids are located at the caudodorsal margin of the mandibular salivary gland ventral to the wing of the atlas, close to the bifurcation of the common carotid artery.

Ox:
- Internal parathyroids are located either at the dorsal margin, the medial aspect or within the parenchyma of each lobe.
- External parathyroids are found medial to the bifurcation of the common carotid artery, close to the origin of the cranial laryngeal nerve from the vagus nerve.

Horse:
- Internal parathyroids are located around the cranial half of each lobe,
- External parathyroids are found along the trachea close to the caudal deep cervical lymph nodes.

Fig. 15-10. Topography of the thyroid gland and the parathyroid gland of a sheep with adjacent structures.

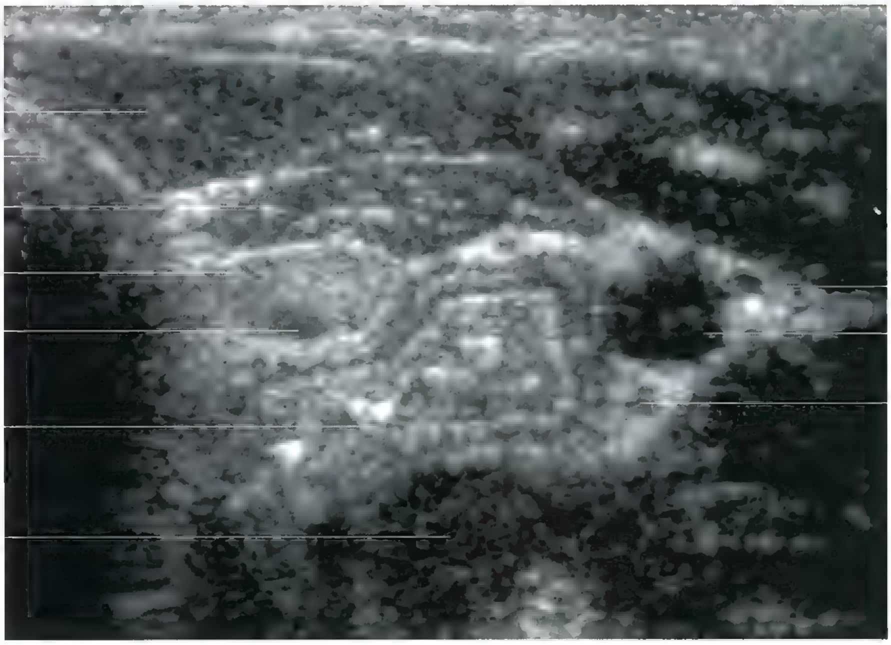


Fig. 15-11. Ultrasonogram of a thyroid gland of a dog, showing the internal parathyroids (courtesy of PD Dr. S. Reese, Munich).

Blood supply, lymphatic drainage and innervation

The parathyroid glands are surrounded by a dense capillary network. They are supplied by small branches of the common carotid artery. Veins open into the jugular vein. Lymphatics drain to the deep cervical lymph nodes.

Sympathetic fibres arise in the cranial cervical ganglion and reach the organs within the adventitia of the supplying arteries. Parasympathetic fibres reach the organ with branches of the caudal laryngeal nerve.

Adrenal glands (glandulae adrenales seu suprarenales)

The paired adrenal glands are located craniomedial to the corresponding kidney in a retroperitoneal position at the roof of the abdomen. They derive their name from this position only and have no functional relationship with the kidneys. Each adrenal gland is composed of two structurally and functionally different endocrine tissues of different embryological origin:

Fig. 15-12. Thyroid gland of a dog, left lobe (courtesy of PD Dr. S. Reese, Munich).

Fig. 15-13. Thyroid gland of a pig (courtesy of PD Dr. S. Reese, Munich).

- Outer cortex,
- Inner medulla.

The **outer cortex** is lighter in colour, radially striated originating from mesenchymal cells of the mesoderm. The **medulla** is darker and of ectodermal origin, originating from sympathetic tissue, thus it represents a sympathetic paraganglion. The adrenal glands are often asymmetrical and irregular and their form and size varies greatly among species and individuals (Fig. 15-5 to 8 and 19). Sectioning of the gland reveals the outer striations of the cortex, enabling easy differentiation from other structures, including lymph nodes. Medullary tissue surrounds the central vein, which in turn is surrounded by the cortex and covered by the fibrous capsule (Fig. 15-17). The ventral surface is marked by the subtile hilus, through which the adrenal vessels enter.

Function

The adrenal cortex produces **hormones,** called corticoids, which regulate mineral balance (mineralcorticoids) and carbohydrate metabolism (glucocorticoids). Androgenic hormones play a role in formation of the male genital organs.

The **activity of the adrenal cortex** is regulated by the adrenocorticotrophic hormone of the adenohypophysis (ACTH). The **adrenal medulla** produces the neurotransmitters adrenaline and noradrenaline. Adrenaline stimulates the sympathetic nervous system, while noradrenaline influences blood pressure. The adrenal medulla co-ordinates the body's response to acute stress, together with the autonomic nervous system.

Blood supply, lymphatic drainage and innervation

The adrenal glands receive a generous blood supply from various small branches of **neighbouring arteries** (abdominal aorta, renal artery, cranial abdominal artery and caudal phrenic artery). The capillaries take a radiating course from the cortex into the medulla and form a capsular and a medullary network.

The **special architecture** of the blood distribution within the gland may mediate cortical control over adrenaline synthesis. Venous blood, enriched with hormones, pools in the

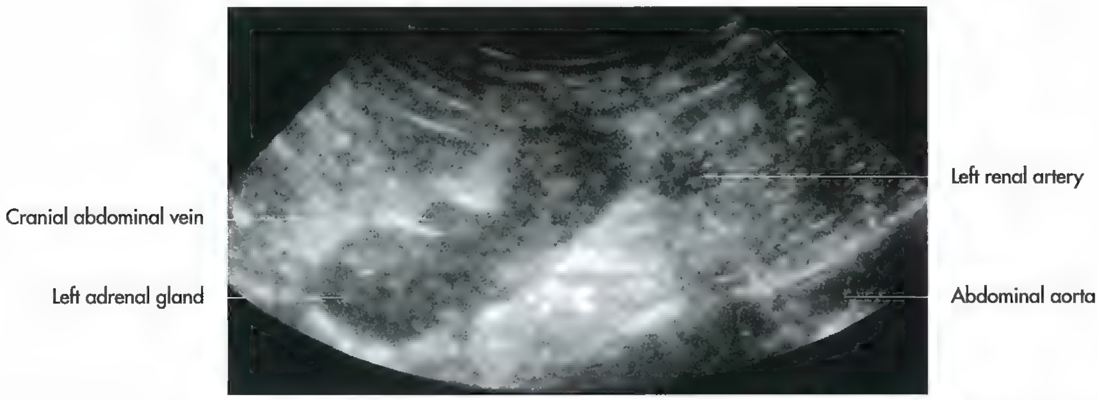


Fig. 15-14. Ultrasonogram of the left adrenal gland of a dog, showing its typical figure eigth shape (courtesy of Dr. Christine Ruppert, Munich).

Fig. 15-15. Left adrenal gland of a pig, paramedian section (courtesy of PD Dr. S. Reese, Munich).

Fig. 15-16. Left adrenal gland of a pig (courtesy of PD Dr. S. Reese, Munich).

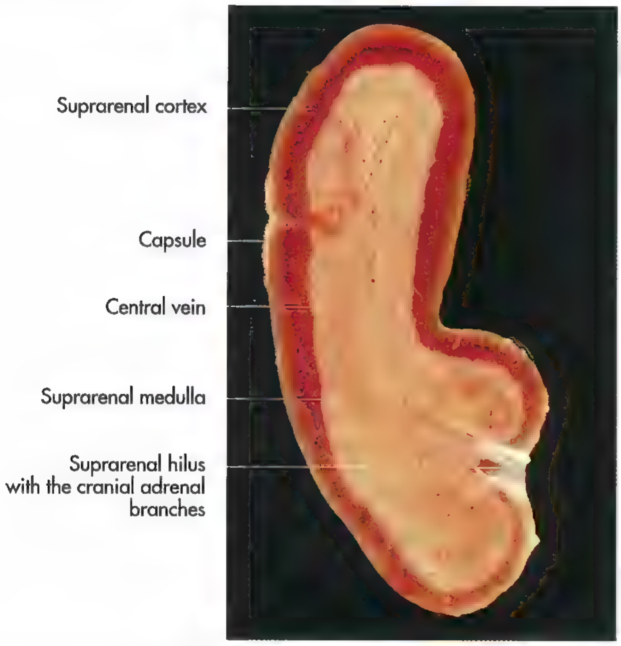


Fig. 15-17. Right adrenal gland of an ox, paramedian section (courtesy of PD Dr. S. Reese, Munich).

Fig. 15-18. Right adrenal gland of an ox (courtesy of PD Dr. S. Reese, Munich).

central vein from which emissary vessels accompany the arteries to join the caudal vena cava.

Lymphatics form a capillary network within the parenchyma of the adrenal gland and drain into the lumbar aortic lymph nodes.

The parenchyma of the adrenal medulla is actually a modified **sympathetic ganglion,** specialised for **neurohormonal release.** It is innervated by preganglionic sympathetic fibres from the **splanchnic nerve.** The cortical cells are modified **postganglionic neurons.**

Paraganglia

Paraganglia are small, nodular masses of **epithelial cells,** which take their embryological origin from the **neural crest**

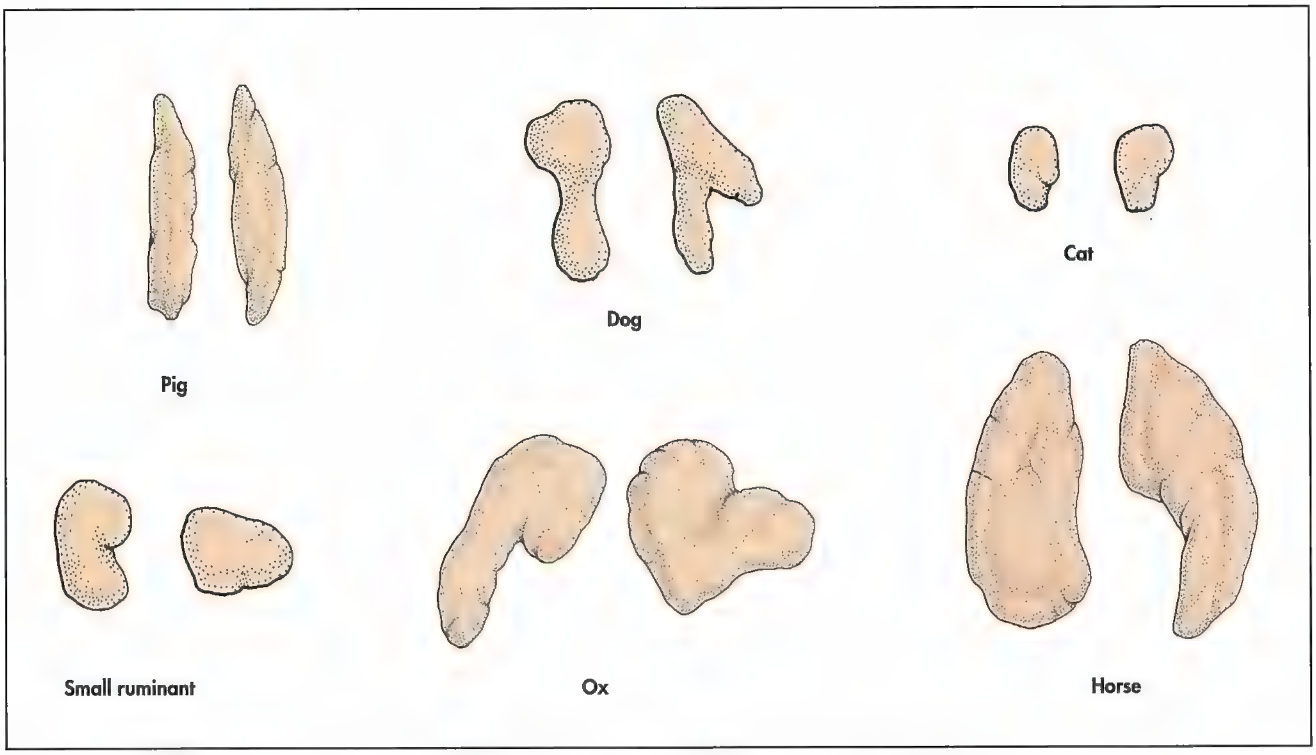


Fig. 15-19. Schematic illustration of the adrenal glands of the different domestic species (Ghetie, 1967).

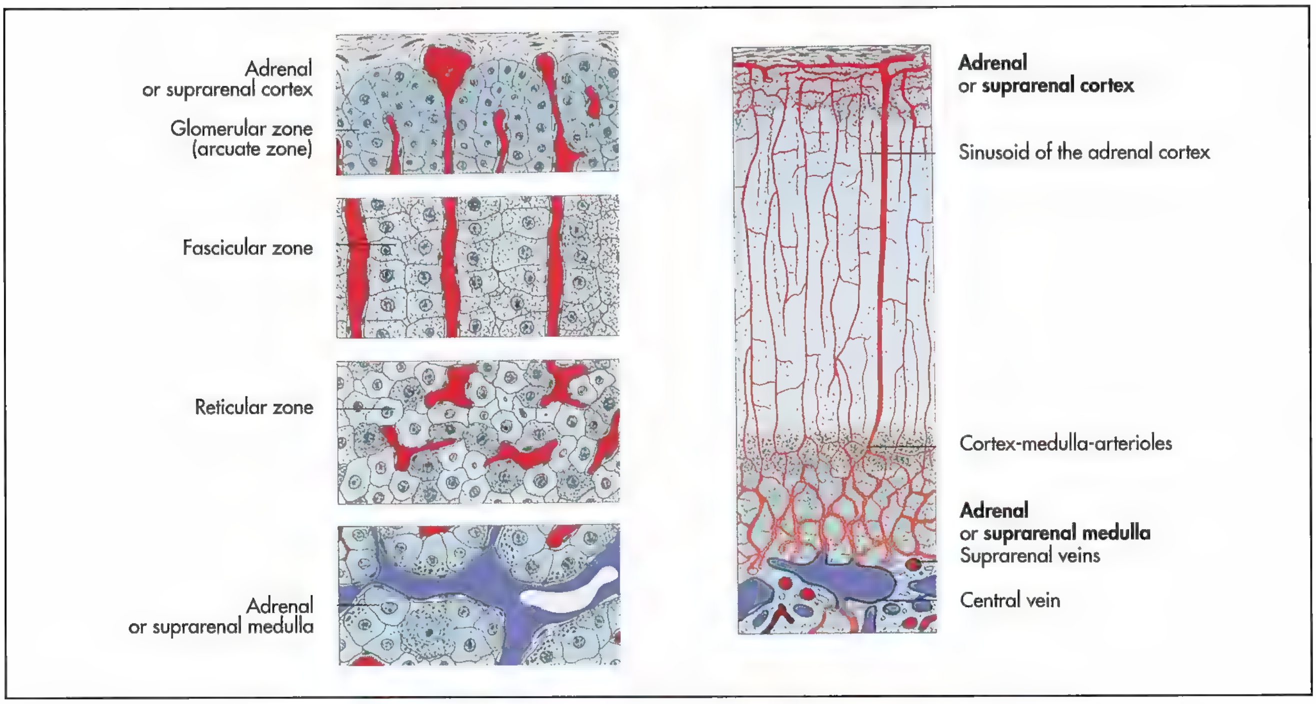


Fig. 15-20. Schematic illustration of the different zones of the adrenal gland with vascularisation (Liebich, 2004).

and contain **adrenaline** and **noradrenaline.** The adrenal medulla is the largest aggregation of these neural crest cells in the body. Other paraganglia are well innervated and are found close to larger arteries. They function as chemoreceptors for the regulation of respiration.

The **carotid body** (glomus caroticum), lies at the bifurcation of the carotid arteries or sometimes within the wall of the **carotid sinus.** It has an irregular shape and varies in size from 1 to 3 mm. It is innervated by a branch (ramus sinus carotici) of the **glossopharyngeal nerve,** but receives addi-

tional branches from the cranial cervical ganglion and the vagus nerve.

The **aortic body** (glomus aorticum) lies on the **aortic arch,** close to the origin of the brachiocephalic trunk. It is smaller than the carotid body and innervated by the depressor branch of the vagus nerve.

The **para-aortic bodies** consist of several paraganglionic masses along the abdominal aorta. Their exact location varies among the different species and individuals. Most sympathetic ganglia also include groups of paraganglionic cells.

Pancreatic islets (insulae pancreatici)

The pancreatic islets, also known as the **"Islets of Langerhans",** constitute the endocrine component of the pancreas. There are 0.5 to 1.5 million islets in man and several thousand islets in the cat and dog, which are supposed to be more numerous in the left pancreatic lobe, than in the right.

The islet cells are of several types: **alpha cells** produce **glucagon** and **beta cells** produce **insulin,** both of which affect carbohydrate metabolism. Insufficient insulin production results in diabetes mellitus. The endocrine pancreas of the dog has served as the classic model for the exploration of insulin-deficiency diabetes by Bantin and Best in 1922. Other cells synthesise somatostatin, which inhibits growth.

The pancreatic islets receive a generous **blood supply** and contain large diameter capillaries. They are the only endocrine glands that are drained by veins, which open into the portal vein.

They receive **autonomic innervation;** sympathetic fibres stimulate the production of glucagon and inhibit that of insulin, parasympathetic fibres stimulate the secretion of insulin.

The gonads as endocrine glands

The testis as well as the ovary, have both an **exocrine** and an **endocrine function,** which are under the control of the hypothalamic-pituitary axis.

The **internal** and **external thecal cells** of the ovary, which enclose a maturing follicle, produce estrogens. After ovulation the corpus luteum forms and produces **progesterone.** It is a transient endocrine structure, which regresses with each estrous cycle, but persists during gestation for a variable proportion of pregnancy. It is vital for maintenance of pregnancy.

The **interstitial cells,** within the connective tissue between the seminiferous tubules of the testes produce **androgens.** They are responsible for the maturation of spermatozoa, and the development of the male genital organs.

The endocrine components of other organs are less distinct and include the renin producing cell clusters of the kidney and the variety of enteroendocrine cells scattered within the gastrointestinal epithelia.

16 Eye (organum visus)

H.-G. Liebich and H. E. König

The eye, the organ of vision, consists of various parts, which are able to receive light stimuli from the environment, register the stimulus and convert it into an electrical signal, which is conveyed to the brain. The receptor neurons contain photosensitive molecules that are chemically transformed by light impulses and react with neural activity of surrounding cells. The resulting signal travels along neurone chains to reach cognitive centres in the brain, where the final image is formed.

Vision is based on a very complex system, that involves all parts of the eye, including its accessory structures (adnexa), as well as various parts of the brain (see chapter 14):

- Eyeball: fibrous, vascular and inner layer of the eyeball, (sclera, cornea, choroid, ciliary body, iris, retina),
- Adnexa: ocular muscles, eye lids, lacrimal apparatus,
- Optic nerve and
- Visual area of the cerebral cortex.

Eyeball (bulbus oculi)

Shape and size of the eyeball

There is considerable **variation between species** in regard to the form and the size of the eyeball between species and individuals. It is roughly spherical in carnivores (20–24 mm in diameter), while in the horse, its width (50 mm) exceeds its height (42 mm) and length (45 mm). The eye of an ox is comparatively smaller than the horse (40–43 cm) that of a comparable sized horse. Corrected for body size, the cat has the largest eyeball, followed by the dog, the horse and the ox and the pig having the smallest.

The **outline of the eyeball** is not evenly rounded, but displays a larger curvature in its posterior part, than in its anterior part, where the cornea bulges forward. The division of the two segments is marked by a visible groove, the scleral groove (sulcus sclerae) (Fig. 16-1).

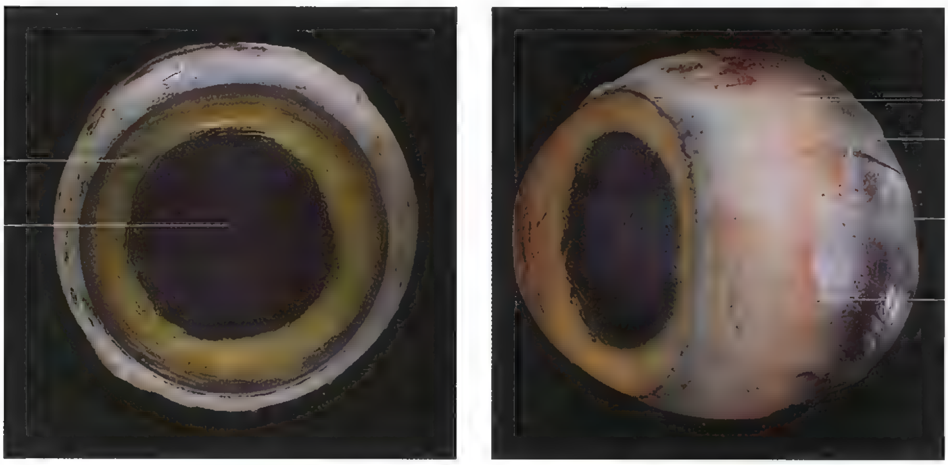


Fig. 16-1. Eyeball of a cat, anterior aspect (left image) and anterior-oblique aspect (right image) (König, 1992).

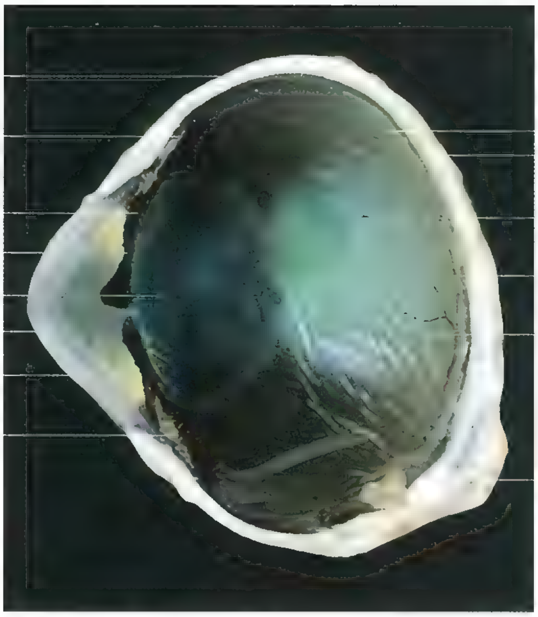


Fig. 16-2. Eyeball of an ox, vertical section, vitreous body removed.

Directional terms and planes of the eyeball

The **vertex of the cornea** is designated the **anterior pole** of the eye (polus anterior) and the point directly opposite to it is the **posterior pole** (polus posterior) (Fig. 16-1).

The line connecting the anterior and posterior poles and passing through the centre of the lens is the **external axis** of the eyeball (axis bulbi externus), also referred to as the **optic axis** (axis opticus). The **internal axis** of the eyeball (axis bulbi internus) extends from the posterior side of the cornea to the internal surface of the retina.

The **equator of the globe** has its maximum circumference located midway between the poles. Lines connecting the poles on the surface of the globe are called **meridians.** For descriptive purposes, main vertical and horizontal meridians are used to divide the globe into four quadrants.

The **optic axis forms** an angle of approximately 20° with the median plane in the cat, 30–50° in the dog, 10–40° in the ox and 90° in the horse. In general, predatory species have eyes set well forward, while hunted species carry their eyes more laterally. The lower the degree of divergence, the larger the field of **binocular vision.** In the horse the right and left field of vision hardly overlap, thus it is able to constantly visualise a large segment of its surroundings, with only a little capacity of binocular vision.

When referring to the eye, anterior (in front) and posterior (behind) are used instead of rostral and caudal, temporal, and nasal are used instead of lateral and medial to describe location.

Structure of the eyeball

The wall of the eyeball is formed by **three concentric layers** (tunicae), which enclose the interior of the eyeball, thus enclosing its other structures (Fig. 16-2, 3 and 5). The interior of the eyeball is divided into three chambers (camerae bulbi):

- Anterior chamber (camera anterior) between the cornea and iris,
- Posterior chamber (camera posterior) between iris, ciliary body and lens and
- Vitreous chamber (camera vitrea) behind the lens, surrounded by retina.

The **layers of the eyeball** (Fig. 16-3) are the :

- Fibrous layer of eyeball (tunica fibrosa bulbi): sclera and cornea,
- Vascular layer of eyeball (tunica vasculosa bulbi): choroid (choroidea), ciliary body (corpus ciliare) and iris and
- Inner layer of eyeball (tunica interna bulbi): nonvisual retina (pars caeca retina) and optic part of retina (pars optica retinae).

Fibrous layer of eyeball (tunica fibrosa bulbi)

The fibrous outer layer is composed of very dense collagenous tissue, which is greatly responsible for the shape of the eye. It is composed of two parts: the opaque, whitish sclera, that encloses approximately the posterior three-quarters of the globe and the transparent cornea, that covers the anterior part of the globe (Fig. 16-2 and 3). The two components meet at the corneoscleral junction, also referred to as corneal limbus.

Sclera

The **substantia propria** of the sclera consists of a dense network of collagen fibres in parallel orientation. Some elastic fibres are dispersed within this collagenous network, that help to resist the internal pressure of the eye as well as the considerable forces it is subjected to by the extra-ocular muscles (Fig. 16-3).

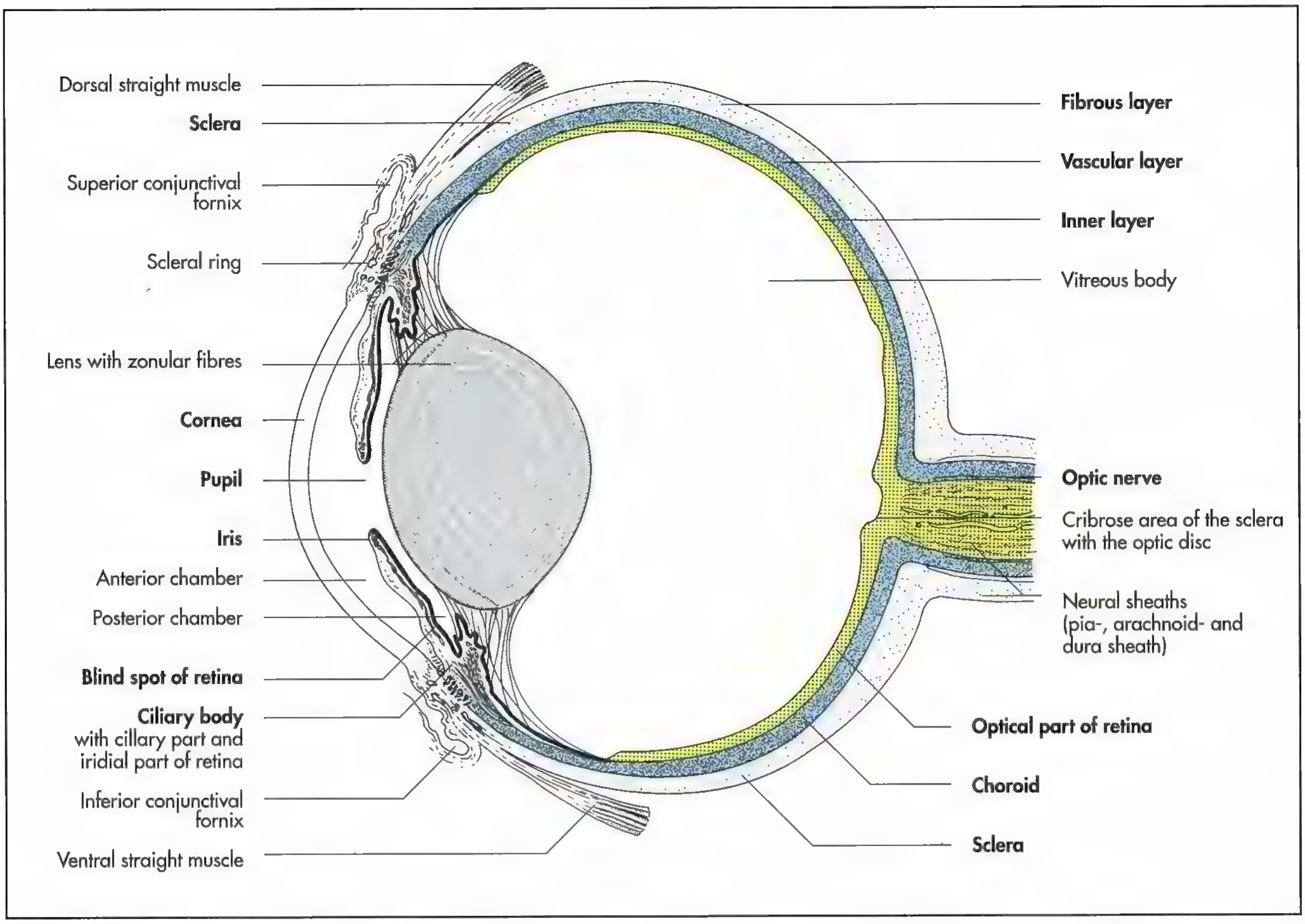


Fig. 16-3. Eyeball in sagittal section (Liebich, 2004).

The sclera varies in **thickness,** being thinnest near to the equator (up to 0.5 mm) and gaining in thickness towards the posterior pole of the eye (up to 2 mm). Ventrotemporally the sclera has many fenestrations, through which the optic nerve and blood vessels pass (area cribrosa sclerae). The trabeculae of the cribrose area continue caudally as the connective tissue septae of the optic nerve.

At the **corneoscleral junction,** the inner surface of the sclera is marked by a **small ridge** (annulus sclerae), where the **ciliary muscle** attaches. The outer surface is marked by the **scleral groove** (sulcus sclerae), which is especially prominent in carnivores.

The **scleral venous plexus,** through which the **aqueous humor** drains, is located between these two structures and is important for the regulation of the **ocular pressure.** An impediment of the aqueous outflow leads to an increase in ocular pressure and affected animals may develop a **glaucoma.**

The sclera is covered by conjunctiva close to the corneoscleral junction, which reflects onto the surface of the globe as the bulbar conjunctiva.

Cornea

The cornea forms the anterior, **transparent segment** of the fibrous layer of the eyeball and bulges forward. Its proper substance consists of parallel fibres of **collagen,** that are arranged in a lamellar form. The highest point of the cornea is called the **vertex,** its periphery, the **limbus.** The cornea of carnivores is rounded, while it is oval in ungulates with an obtuse nasal canthus and an acute temporal canthus.

The cornea is composed of five layers:

- Anterior epithelium (epithelium anterius),
- Anterior limiting lamina or Bowman-layer (lamina limitans anterior),
- Substantia propria,
- Posterior limiting lamina or Descemet-membrane (lamina limitans posterior) and
- Posterior epithelium (epithelium posterius) or endothelium of the anterior chamber (epithelium camerae anterioris).

The **anterior epithelium** consists of several layers of squamous cells and is continuous with the bulbar conjunctiva. Its outer surface is kept moist by the precorneal tear film, which provides protection to these cells. This precorneal film consists of serous, mucoid and fatty components. The anterior epithelium forms a barrier, that reduces water diffusion into the proper substance of the cornea (Fig. 16-6).

Fig. 16-4. Computed tomogram of the head of a dog at the level of the eyes.

The **substantia propria** consists of collagen fibres that are arranged in distinct lamellae, keratocytes, which are flattened between these lamellae, and a watery matrix. Between the collagenous fibres a dense network of non-myelinated, sensory and autonomic nerve fibres extends. The cornea is normally avascular and is nourished by diffusion of molecules from the capillary loops at the corneoscleral junction, the precorneal tear film and the aqueous humor.

The **posterior limiting membrane** is the exaggerated basement membrane of the posterior epithelium. The posterior epithelium is composed of a simple squamous epithelium, which also constitutes the endothelium of the anterior chamber of the eye. It enhances the selective diffusion of water to maintain the transparency of the cornea and excretes proteins for the construction of the posterior limiting layer of the cornea.

Vascular layer of eyeball (tunica vasculosa seu media bulbi, uvea)

The vascular layer of the eyeball is interposed between the sclera and the retina. It is composed of connective tissue, which contains pigment cells, elastic fibres, nervous plexus and a dense network of blood vessels. The vascular layer consists of three parts:

- Choroid (choroidea),
- Ciliary body (corpus ciliare),
- Iris.

It has numerous functions: blood supply, suspension and regulation of the shape of the lens, regulation of the size of the pupil, and production of the aqueous humor.

Choroid (choroidea, uvea)

The choroid is a pigmented, highly vascular layer, that envelops the posterior part of the eyeball (Fig. 16-24).

It is further divided into layers, which are from the **outermost layer** inwards:

- Suprachoroid layer (lamina suprachoroidea),
- Vascular layer (lamina vasculosa),
- Choroidocapillary layer (lamina choroidocapillaris) and
- Basal lamina (lamina vitrea).

The **suprachoroid layer** is a network of delicate fibrils with pigment cells embedded within, which forms a loose connection between the choroid and the sclera.

The **vascular layer** is the thickest part of the choroid and consists of pigmented, lamellar connective tissue. Blood vessels pass within this layer providing vascular support for the inner neuronal layers of the retina. These vessels are the **ciliary arteries** and the **vorticose veins** (aa. ciliares, vv. vorticosae). These send branches into the **choroidocapillary layer,** where they form the inner capillary bed of the choroidea. The dense capillary network of the choroidocapillary layer is responsible for the nutrition of the outer layers of the retina.

Dorsal to the optic papillae is a half-moon shaped area, that has an additional reflective layer between the vascular and the choroidocapillary layer, the **tapetum lucidum** (Fig. 16-20 and 22 to 24).

The tapetum lucidum is present in all domestic mammals other than the pig. It is **cellular in carnivores** (tapetum cellulosum) and **fibrous in herbivores** (tapetum fibrosum). The retina underlying the tapetum is usually **pigment-free.**

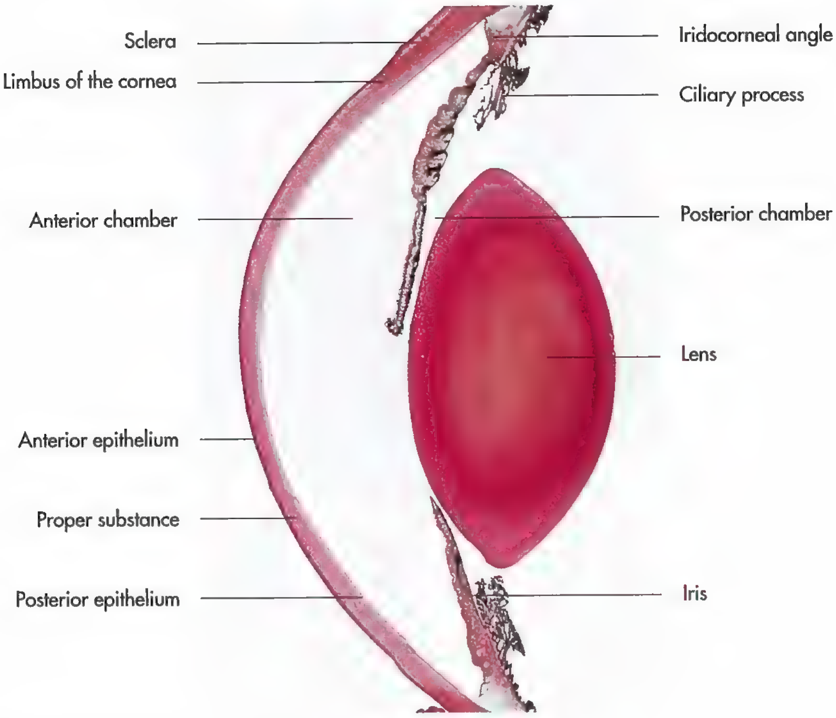


Fig. 16-5. Histological section of the anterior part of the eye of a cat.

The **tapetal cells** contain crystalline rods (zinc and cysteine), that are highly reflective and results in multiplication of the light stimulus to the light-sensitive receptor cells of the retina. Thus, it aids vision during dawn and night. The tapetum lucidum has a distinctive colour in the different species and breeds (yellow in the cat, green in the dog, blue-green in the ox and horse) and accounts for the iridescent appearance of an animal's eye.

Ciliary body (corpus ciliare)

The ciliary body is the thickened middle segment of the vascular tunic, between the choroid and the iris (Fig. 16-18). This is an elevated ring from which ridges, the **ciliary processes** (processus ciliares) radiate towards the lens in the centre. Zonular fibres extend from the ciliary processes to the equator of the lens to suspend it around its periphery. The ciliary body is in contact with the vitreous and forms the lateral borders of the posterior chamber. Its outer surface is covered by the sclera, its inner surface by the **nonvisual part of the retina** (pars caeca retinae).

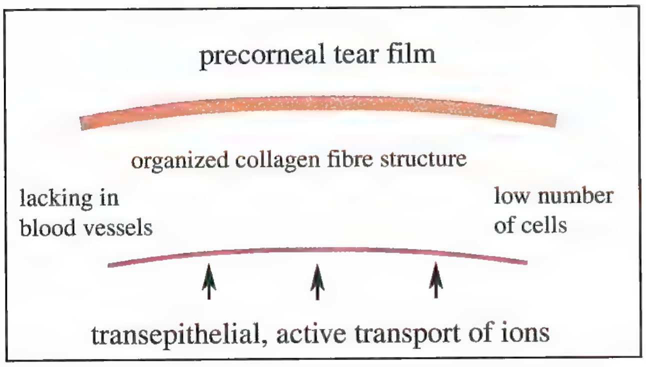


Fig. 16-6. Schematic illustration of the structural and physiological factors, that account for the transparency of the cornea.

The ciliary body can be subdivided into the:

- Ciliary ring (orbiculus ciliaris, pars plana),
- Crown of ciliary body (corona ciliaris, pars plicata): post- and prelenticular part.

The **ciliary ring** (orbiculus ciliaris) constitutes the posterior portion of the ciliary body that is relatively flat, with the exception of a few fine **radiating folds** (plicae ciliares). It is covered by fibres of the ciliary zonule. The boundary between the pars ciliaris retinae and the pars optic retinae is demarcated by a slightly undulating line, the **ora serrata**. The boundary towards the corona ciliaris is indistinct (Fig. 16-12, 14 and 15).

The **corona ciliaris** is the more prominent anterior portion, that contains the **ciliary processes** (Fig. 16-12, 14 and 15). The **ciliary body** is elevated into numerous small, flat, parallel processes, which increase rapidly in height to form tall, thin folds. These loose their outer attachment to the sclera and extend from the base of the ciliary body centrally towards the lens as the ciliary processes. There are approximately 70–80 ciliary processes in the dog and more than 100 in the ox and horse.

The **lens** is fixed in position by the **ciliary zonule** (zonula ciliaris), a delicate suspensory apparatus, which is composed of a highly ordered array of zonular fibres. The zonule lies posterior to the iris and ciliary body and separates the posterior


Fig. 16-7. Right eye of a cat.


Fig. 16-8. Left eye of a dog.

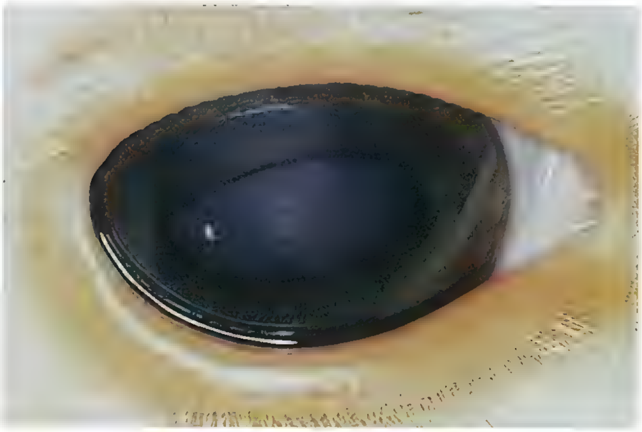


Fig. 16-9. Right eye of an ox.


Fig. 16-10. Left eye of a horse.

chamber from the vitreous. They anchor the lens to the postlenticular part of the ciliary body, while no zonular fibres insert to the short prelenticular part (Fig. 16-11 and 18). The ciliary processes of the prelenticular part show plump folds on their surface (Fig. 16-19).

The **ciliary epithelium** produces the aqueous humor, which is secreted into the posterior chamber. It flows into the anterior chamber through the pupil and drains through the venous plexus of the sclera at the iridocorneal angle (Fig. 16-11).

The **ciliary body** forms a symmetrical ring in carnivores, but is asymmetrical in ruminants and the horse, in which the visual part of the retina extends further forward. Elastic fibres, pigment cells, blood vessels and the ciliary muscle fibres are embedded in the connective tissue of the ciliary body.

The **ciliary muscle** (m. ciliaris) is a smooth muscle, which enables the lens to change its shape to focus on near or distant objects **(accommodation).** It is comparably weak in the horse, but stronger in carnivores. It receives **parasympathetic innervation** from the **ciliary ganglion** and sympathetic innervation. Parasympathetic innervation causes the ciliary muscle to contract, thus the lens becomes more rounded and focuses on near objects. **Sympathetic impulses** cause relaxation of the ciliary muscle, flattening of the lens and focuses on distant objects.

Iris

The iris is the continuation of the ciliary body and constitutes the most anterior part of the vascular layer. It is a thin ring of highly vascular tissue, that rests against the anterior surface of the lens. The **free margin of the iris** (margo pupillaris) borders the **pupil** through which light enters the posterior part of the eye. The **periphery of the iris** (margo ciliaris) is continuous with the ciliary body and the iridocorneal angel. The iris separates the space between cornea and lens into **anterior** (camera anterior bulbi) and **posterior chambers** (camera posterior) of the eye, which communicate through the pupil (Fig. 16-2 and 11).

The **anterior surface of the iris** is covered by a discontinuous layer of epithelial cells. The underlying stroma consists of delicate bundles of collagen fibres with blood vessels, smooth muscle fibres, pigmented cells and nerve fibres.

The **collagen fibres** are able to adapt to the **dilatation** (mydriasis) or **constriction** (miosis) of the pupil. There is a dense network of blood **vessels within the stroma** (circulus arteriosus iridis major et minor), that fulfil nutritive as well as stabilising functions. Basket-like networks of collagen fibres are formed around the blood vessels to protect microcircula-

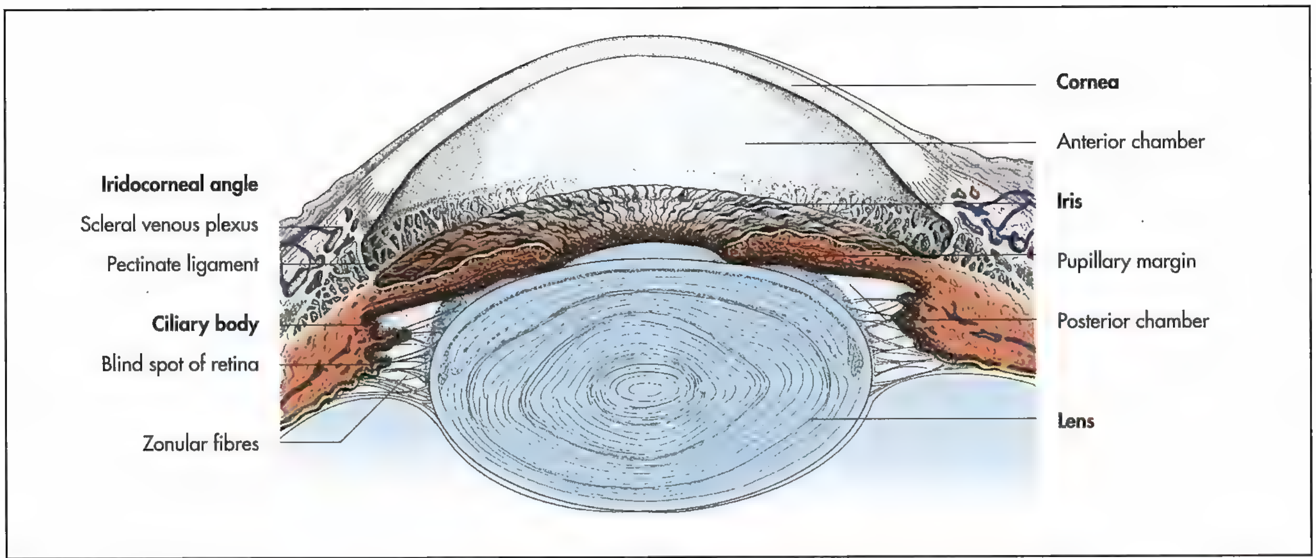


Fig. 16-11. Anterior part of the eye in section, schematic (Liebich, 2004).

tion during contraction or dilatation of the pupil. The **stroma** contains **two smooth muscles,** the sphincter and dilator of the pupil, which regulate the size of the pupil and consequently the amount of light that reaches the retina. The **sphincter muscle** (m. sphincter pupillae) consists of circular smooth muscle fibres near the pupillary margin of the iris. In animals with an oval pupil (cat, sheep, ox) the muscle is enforced by additional fibres, which have a grid-like arrangement and result in a horizontal or vertical slit-like pupil during miosis (Fig. 16-7 to 10 and 14 to 17). The sphincter muscle receives **parasympathetic innervation.**

The **dilator of the pupil** (m. dilatator pupillae) is composed of radially arranged muscle fibres, forming a meshwork that fills the posterior part of the iris almost completely. It is derived from the neuroepithelium of the pars iridica retinae. The dilator muscle is innervated by sympathetic fibres.

The **pigmented cells of the iris** contain **melanin,** which protects the retina from intense light. The number and size of the pigments determines the **"colour of the eye",** that is genetically determined by several codominant genes. If the collagen fibres are densely packed and there is a paucity of pigmented cells within the iris stroma the eye appears to be blue or grey (pig and goat). If there are many pigmented cells within a thin network of collagen fibres the iris is coloured dark brown (ox, horse). Fewer pigmented cells result in a lighter, yellow colour of the iris (dog, pig, small ruminants). In albinos, the iris is completely devoid of pigment. Their eyes appear red, due to the blood supply in this area, which is not obscured by pigment (Fig. 16-7 to 10, 16 and 17).

The **posterior surface of the iris** (facies posterior) is lined by the pigmented inner layer of the iridial retina and the **pigmented epithelium** (epithelium pigmentosum). The upper and lower pupillary margin of the iris of ruminants and horses show irregular outgrowths, that contain coils of capillaries, the **granula iridica** (corpra nigrans). In small ruminants and in the horse the granula iridica may enclose cystic structures. It is hypothesised that the granula iridica secrete aqueous humor.

Innervation of the iris and of the ciliary body

Muscles and vessels of the iris and the ciliary body receive **sympathetic** and **parasympathetic fibres** from the ciliary ganglion, with the **short ciliary nerves** (nn. ciliares breves). The **postganglionic sympathetic** fibres supply the dilator pupillae muscle, the blood vessels of the iris and the ciliary processes. The parasympathetic fibres arise from the **oculomotor nerve** and supply the sphincter pupillae muscle and the ciliary muscle, forming a reflex arc.

Drugs with a parasympathetic or cholinergic action, such as **pilocarpine** or **carbachol** stimulate the constriction of the pupil and contraction of the ciliary muscle. Parasympathetic action on the eye can be blocked by topical administration of natural alkaloids, such as atropine and hyoscine, resulting in passive mydriasis and paralysis of accommodation. Sympathetic action can be induced by **phenylephrine** and **adrenaline.**

Inner layer of the eyeball (tunica interna bulbi, retina)

The inner layer of the eyeball is the retina. It develops from an outgrowth of the diencephalon, the optic vesicle, to which it remains connected by the optic nerve. The optic nerve, therefore, is actually a tract of the central nervous system. Further details on the embryological development of the eye can be found in standard embryology textbooks.

The retina can be divided into following parts:

- Non-visual retina (pars caeca retinae),
  - Ciliary part of retina (pars ciliaris retinae),
  - Iridial part of retina (pars iridica retinae) and
- Optic part of retina (pars optica retinae).

The **nonvisual part of the retina** lines the anterior part of the eye and covers the posterior surface of the iris. It consists of an inner and outer epithelium, that are both single layered.

Fig. 16-12. Posterior aspect of the eye of a cat, showing ciliary body and lens (equatorial section).

Fig. 16-13. Anterior aspect of the eye of a horse, showing iris, pupil and iridial granules (courtesy of Prof. Dr. H. Gerhards, Munich).

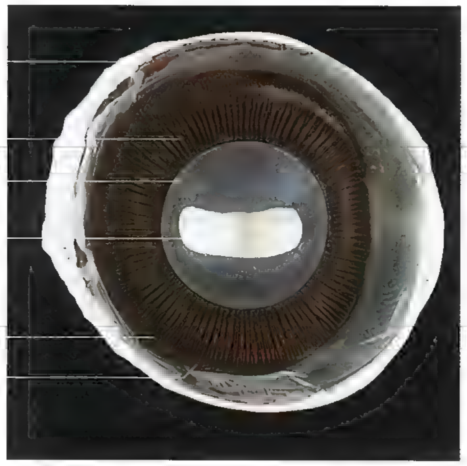


Fig. 16-14. Posterior aspect of the eye of an ox, showing ciliary body and lens (equatorial section), mydriasis.

Fig. 16-15. Posterior aspect of the eye of an ox, showing ciliary body, lens removed (equatorial section), miosis.

Fig. 16-16. Anterior aspect of the eye of a horse, showing iris, pupil and iridial granules (courtesy of Prof. Dr. H. Gerhards, Munich).

Fig. 16-17. Anterior aspect of the eye of a horse with heterochromia of the iris, showing iris, pupil and iridial granules (courtesy of Prof. Dr. H. Gerhards, Munich).

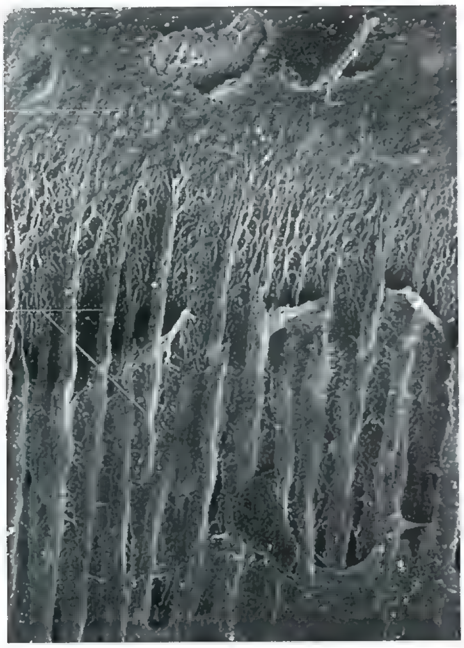


Fig. 16-18. SEM image of the ciliary corona of an ox (courtesy of PD Dr. S. Reese, Munich).

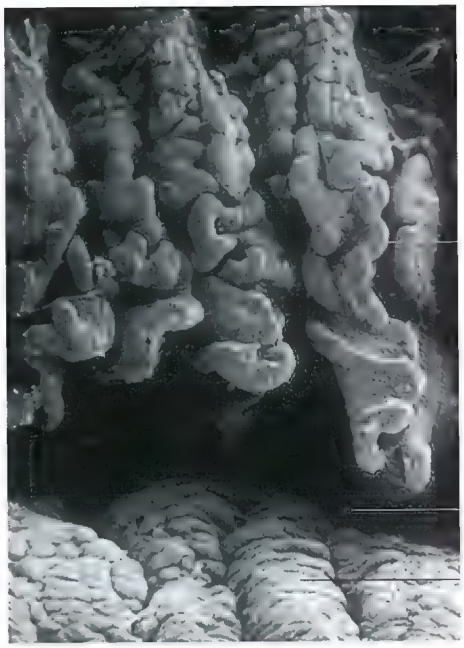


Fig. 16-19. SEM image of the prelenticular ciliary processes of an ox (courtesy of PD Dr. S. Reese, Munich).

The **outer layer** is heavily **pigmented,** while the **inner layer** is **unpigmented.**

The **ora serrata** is the demarcation between the **non-visual** and the **optic part of the retina** (Fig. 16-14 and 15). The optic part lies posterior to the ora serrata and lines the posterior part of the eye. It is responsible for the transduction of photic energy into chemical energy and finally into electrical impulses, that are transmitted along the optic nerve to the visual centres of the brain. It is considerably thicker than the nonvisual part and consists of:

- Outer pigmented layer (stratum pigmentosum),
- Inner neural layer (stratum nervosum), including photoreceptor and synapsing layers.

Pigmented layer (stratum pigmentosum retinae)

The pigmented layer develops from the outer wall of the optic cup and forms the **outermost layer of the retina,** immediately adjacent to the choroid. It consists of a single layered, cuboidal epithelium that is heavily pigmented and surrounds the photoreceptor cells **(rods** and **cones).** Light passing through the photoreceptor cells is absorbed by the pigmented layers of the retina and the choroid, thus reducing scatter, thereby enhancing contrast. In the area of the tapetum lucidum, the pigmented layer of the retina **lacks pigment** (Fig. 16-24) and the light is reflected back through the photoreceptor layer. This is thought to be and adaptation for improved vision in low levels of illumination.

Neural layer (stratum nervosum retinae)

The neural layer of the retina develops from the **inner wall of the optic cup** and includes **photoreceptors, interneurons, ganglion cells** and **associated stromal cells** (Müller cells). The Müller cells are **glial cells,** that are provide nutritional support for the retinal neurons. Their extensions form inner and outer membranes between neurons. (For a more detailed description see histology textbooks.)

The **retinal neurons** form chains of three successive, interconnected neurons that can be easily distinguished histologically (Fig. 16-24). The following layers can be distinguished within the neural layer of the retina from the outside to the inside:

- **I. Neuron**
  - Neuroepithelial layer (stratum neuroepitheliale): Rods and cones,
  - Outer nuclear layer (stratum nucleare externum),
  - Outer plexiform layer
  - (stratum plexiforme externum),
- **II. Neuron**
  - Inner nuclear layer (stratum nucleare internum): Bipolar neurons,
  - Inner plexiform layer (stratum plexiforme internum),
- **III. Neuron**
  - Ganglionic layer (stratum ganglionare): multipolar neurons and
  - Layer of nerve fibres (stratum neurofibrarum).

The **photosensitive receptor cells** of the retina are the rods and cones. The **rods** are highly sensitive receptors for **black and white** (night), while the **cones** are concerned with **colour vision** (day). The photoreceptor segments of the rods and cones are situated outward, adjacent to the pigmented epithelium. The **rods** contain membranous discs filled with **rhodopsin,** which is responsible for the transduction of light energy in-

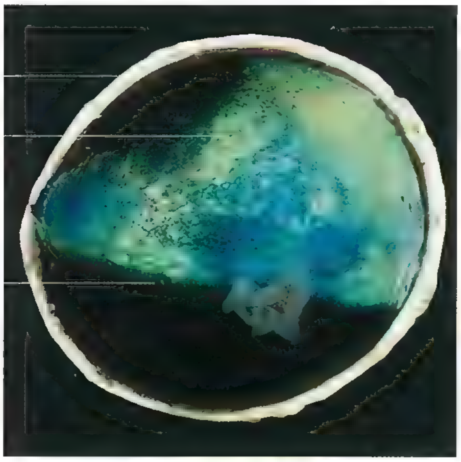


Fig. 16-20. Ocular fundus of an ox, retina partly removed, equatorial section, anterior aspect.

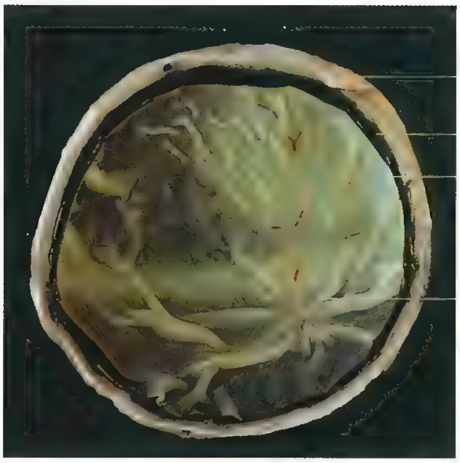


Fig. 16-21. Ocular fundus of an ox, equatorial section, anterior aspect.

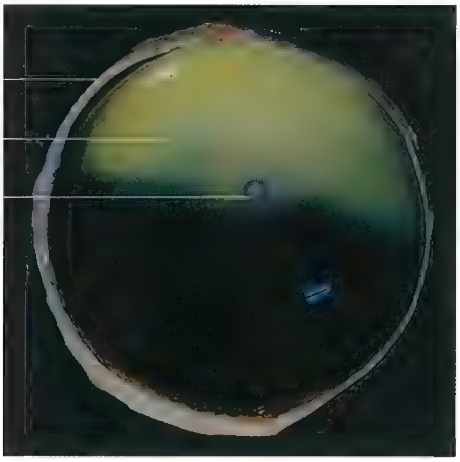


Fig. 16-22. Tapetum lucidum of a cat, equatorial section, anterior aspect (König, 1992).

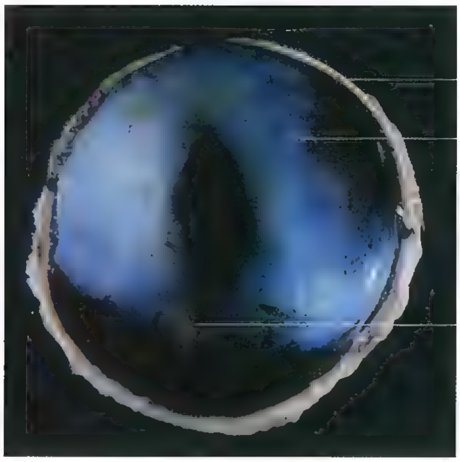


Fig. 16-23. Tapetum lucidum of a cat, equatorial section, anterior aspect.

to chemical energy. New discs are continuously produced and moved to the end of the photoreceptor segments, where they undergo phagocytosis by the pigmented cells. **Cones** have a similar architecture, but do not contain rhodopsin as photosensitive pigment, but others, such as **iodopsin.** For a more detailed description see histology textbooks.

Cats appear to be able to differentiate between the colours green and blue, but have otherwise a poor colour vision. Ruminants and horse are not able to see the colours red and blue, while pigs have a colour spectrum that is similar to those of humans. The dog has a dichromate vision, in that it is able to distinguish between stimuli having predominantly short and long wavelengths.

The **outer nuclear layer** contains the cell bodies of the **photoreceptor cells.** The axons of which synapse with the dendrites of the second, bipolar neurone to form the **outer plexiform layer.** The **inner nuclear layer** contains the cell bodies of the **secondary neurons** and the associated horizontal cells, that form interneural connections between the photoreceptor cells and secondary neurons. The axons of the secondary neurons synapse with the dendrites of the tertiary, multipolar neurons of the ganglionic layer to form the **inner plexiform layer.** Interneurons synapse with axons of the bipolar neurons, as well as with the dendrites of the cells of the **ganglionic layer.** The ganglionic layer consists of multipolar and smaller **autonomic neurons.** Their axons form the layer of nerve fibres that pass on the inside of the retina to the **optic disc** (discus nervi optici) (Fig. 16-20 to 23).

The **axons of the ganglionic cells** are concentrated at the optic disc, where they pass through the **cribriform area** (area cribrosa) of the sclera to form the **optic nerve** (Fig. 16-25). The form of the optic disc ranges from round to oval or triangular. It is a **blind spot,** since there are no photo-receptor cells. It is located in the ventronasal quadrant of the retina in the cat, in the median part of the perpendicular principal meridian in the dog and in the ventrotemporal quadrant in the other domestic mammals.

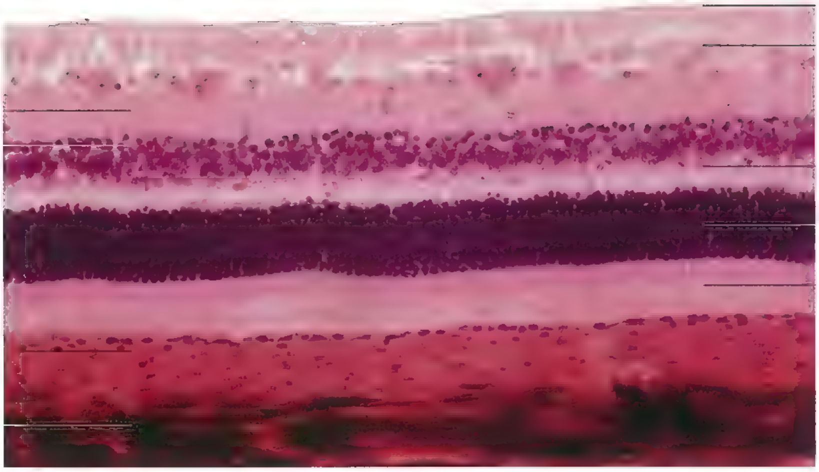


Fig. 16-24. Histological section of the optic part of the retina of a horse from the area of the tapetum lucidum (Liebich, 2004).

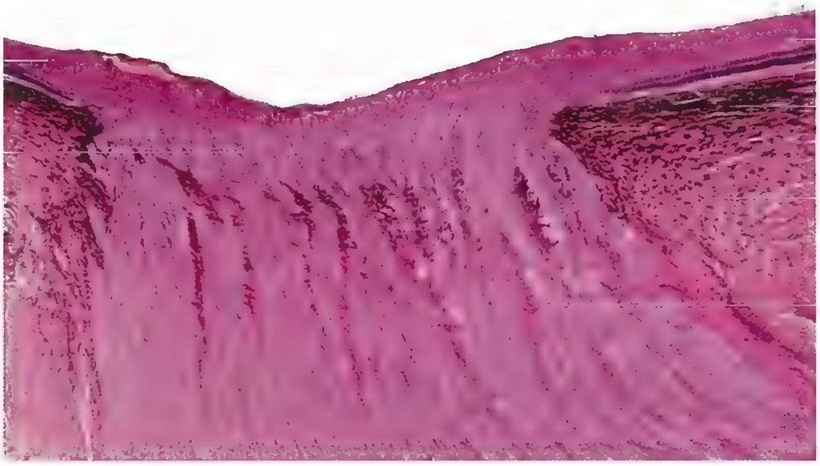


Fig. 16-25. The optic disc of a goat (Liebich, 2004).

Area centralis retinae

Located a short distance dorsotemporal to the optic disc is an area of maximum optical resolution, the macula. In humans it has a distinct yellow colour, which is not present in animals. In this area the number of photoreceptor and neural cells is increased and in humans it consists predominantly of cones

Area centralis striaeformis

The retina of the horse, the pig and ruminants shows strip-shaped areas of lighter colour dorsal to the optic disc. These areas include a high number of cones and neural cells. It is hypothesised that they play an important role in the recognition of movements. The part of the retina and all associated structures that can be visualised with the ophthalmoscope are referred to as the ocular fundus.

Nutrition of the retina

The photoreceptor cells of the retina are nourished by **diffusion** from the capillary network of the choroid. To diffuse to the photoreceptor cells the molecules must pass through the pigmented layer. The outer membrane of the **Müller cells** form a diffusion barrier towards the inner layers of the retina.

In cases of retinal detachment the retina usually separates along the line of the embryonic intraretinal space between the pigment epithelium and the neural layers of the retina. Thereby

the nutritional supply to the rods and cones is removed and the photoreceptor cells degenerate.

The remaining layers of the retina are supplied by the **retinal arteries,** which originate from the **short posterior retinal arteries.** They enter the eyeball close to the optic disc and branch into numerous arterioles, forming a species-specific pattern. In the dog and the cat the arterioles radiate toward the periphery. Except for the area centralis the retina is uniformly vascularised in these species. The retinal blood vessels of the horse have only a few branches, that form a ring-like pattern. In the ox they form a cross-like pattern. The retina is drained by **venules,** which unite and leave the globe through the optic disc as the central vein of the retina.

Optic nerve (nervus opticus)

The optic nerve, or **second cranial nerve** is actually a **tract of the brain,** which by convention is called a nerve. It is formed by the axons of the multipolar cells of the ganglionic layer of the retina. The unmyelinated axons of the ganglionic cell layer collect at the optic disc. Here they become myelinated, when they pass through the area cribrosa of the sclera to form the optic nerve. Its sheath is formed by the meninges, which include subarachnoid and subdural spaces.

The **optic nerve** is about 1mm in diameter in the cat, 2mm in the dog and 5mm in the horse. It passes caudally within the orbital fat pad and the retractor muscle of the bulbi and enter the skull through the **optic foramen** and the **optic canals.** In all mammals a majority of the fibres cross to the contralateral side at the **optic chiasm.**

The fibres continue as the optic tract and pass to the **lateral geniculate nucleus** and the **thalamus** from which fibres project onto the **visual area of the cerebral cortex.** The autonomic fibres of the optic nerve terminate in the **supraoptic** and **paraventricular nucleus** of the hypothalamus, where they form **retino-hypothalamic tracts.**

Structures of the inner eye

Lens

The lens is a transparent, biconvex structure suspended by the ciliary zonule (Fig. 16-3, 11, 26 and 27). It has anterior and posterior poles, an equator and a central axis. The posterior surface is usually more convex than the anterior. During accommodation, the convexity of the lens changes. In the adult the lens is avascular and nutrition is provided by diffusion from the aqueous and vitreous humor.

Structures of the lens are:

- Capsule of the lens (capsula lentis),
- Lens epithelium (epithelium lentis),
- Lens fibres (fibrae lentis).

The entire lens is covered by the **lens capsule,** which consists of a semipermeable, basement membrane, secreted by the cells of the **lens epithelium.** It is highly refractile and elastic. The **zonular fibres,** which suspend the lens, insert into the superficial layers of the lens capsule (Fig. 16-30). The lens rests in a depression in the vitreous, which is tightly adherent to the posterior capsule of the lens. The **lens** is **ectodermal** in origin. It develops from an invagination of the surface epithelium that overlies the optic cup and pinches off to form the lens vesicle. The cells from the posterior wall elongate until they reach the anterior epithelium, obliterating the cavity of the vesicle. These cells then lose their nuclei to become **lens fi-**

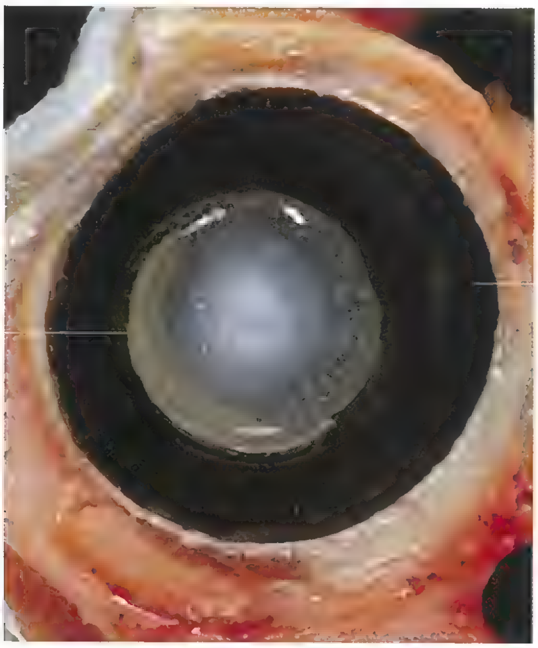


Fig. 16-26. Lens and iris of a dog, anterior aspect (courtesy of PD Dr. J. Maierl, Munich).

Fig. 16-27. Lens and vitreous of a cat.

Fig. 16-28. Iris of a cat, lens removed, posterior aspect.

bres. Consequently, there is a cuboidal lenticular epithelium only on the anterior aspect of the lens in the adult. Throughout life, the epithelium continues to proliferate: Cells at the equator elongate along the meridians until their apices reach the poles. As successive cell layers accumulate, the deeper cells lose their nuclei, but remain viable as lens fibres. This manner of growth results in a lamellar architecture of the lens, resembling an onion in cross section.

Within each layer the fibres are arranged to loop from pole to pole, but their apices do not all meet at a single point at each pole. Instead, the junctions form distinct linear markings, the **lens sutures** (radii lentis). On the anterior surface the lens sutures form an **upright Y,** on the posterior surface the **Y is inverted.** The growth rate of the lens is usually species specific and there is a direct correlation between dry lens weight and age.

Each lens fibre consists of several successive hexagonal epithelial cells, which have flexible interconnections that provide elastic properties to the lens. The **extracellular matrix of the lens fibres** is composed of water (70%), membrane proteins and microfilaments (actin, vimentin, fibronectin). In the cortical part of the lens the fibres are relatively soft, but become firmer and more densely arranged towards the centre, where they form the **nucleus of the lens** (nucleus lentis). The

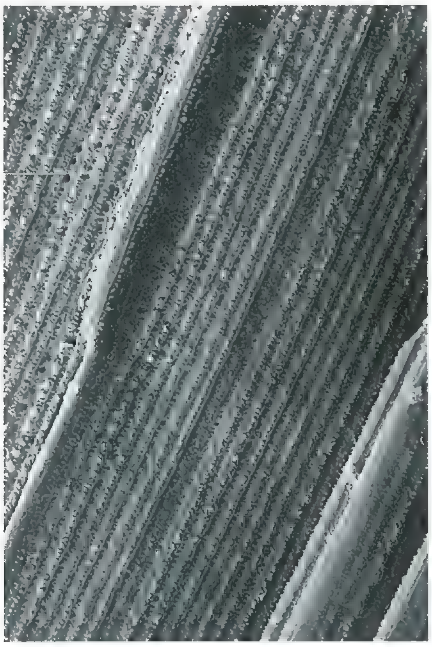


Fig. 16-29. SEM image of the lenticular fibres of an ox, lens sectioned (courtesy of PD Dr. S. Reese, Munich).

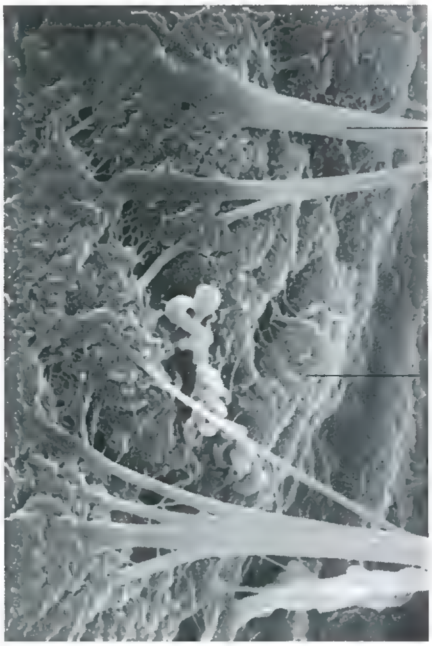


Fig. 16-30. SEM image of the zonular fibres of a cat at their site of insertion to the lens.

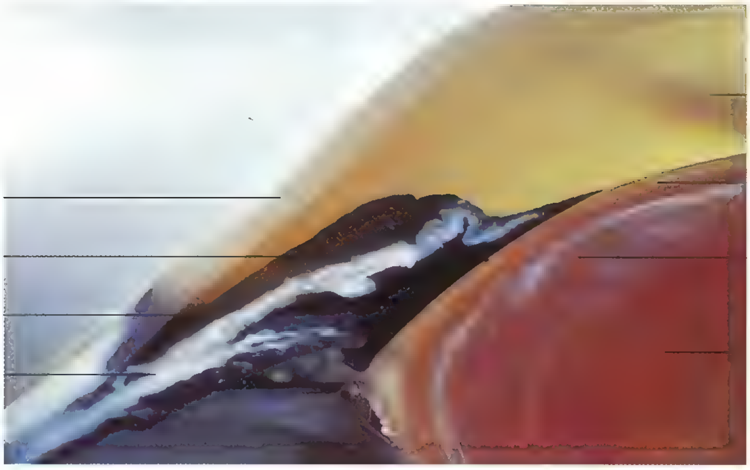


Fig. 16-31. Iridocorneal angle, iris and ciliary body of an ox with part of the anterior eyeball, section.

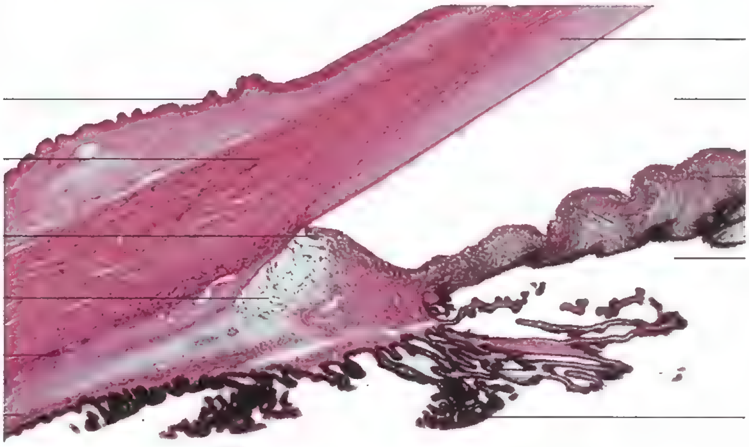


Fig. 16-32. Histological section of the iridocorneal angle of an ox (Liebich, 2004).

nuclear portion of the lens undergoes progressive dehydration and condensation with age, resulting in a much firmer and less elastic lens in older individuals. The **lamellar architecture of the lens** is essential for transparency. Disease processes, which affect lenticular metabolism, result in loss of transparency, forming a **cataract.**

Chambers of the eyeball (camerae bulbi) and aqueous humor (humor aquosus)

There are **three chambers** within the eyeball, the **anterior chamber,** the **posterior chamber** and the **vitreous chamber.**

The **anterior chamber** (camera anterior bulbi) is the space bounded by the posterior surface of the cornea and the anterior surface of the iris and lens. The anterior chamber is in direct communication with the posterior chamber through the aperture of the pupil.

The **posterior chamber** (camera posterior bulbi) is bounded anteriorly by the iris and the ciliary body, posteriorly by the lens capsule and the vitreous. The anterior and posterior chambers are filled with **aqueous humor,** which is produced by an active secretory process from the epithelium of the ciliary body. It is a clear and colourless fluid, containing several electrolytes, glucose, amino acids and ascorbic acid. It is important for the nutrition of the avascular structures of the eye (cornea and lens).

The **aqueous humor** flows from its site of production into the posterior chamber, from here it passes through the pupil into the anterior chamber and drains through the spaces of the **iridocorneal angle** (angulus iridocornealis) to the **scleral venous plexus** (Fig. 16-31 to 35). In the healthy eye the rate of production balances the rate of drainage, thus keeping intraocular pressure constant. Impairment of outflow results in an increase in intraocular pressure **(glaucoma)** leading to retinal atrophy and blindness.

Vitreous body (corpus vitreum)

The **vitreous chamber** is the largest of the three chambers of the eye. It is bounded anteriorly by the lens and the ciliary

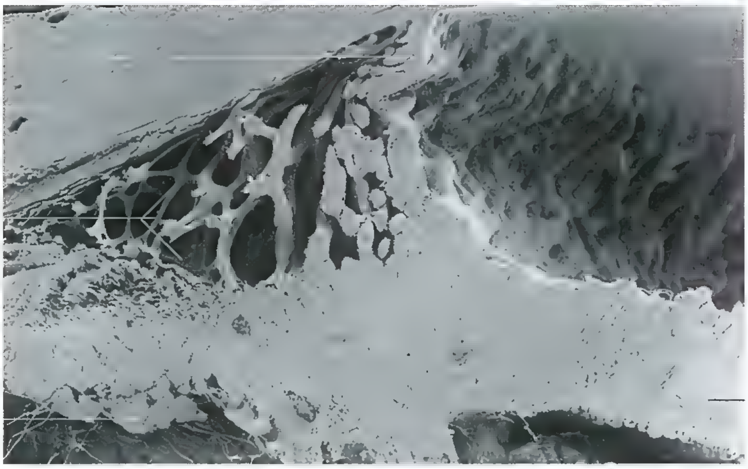


Fig. 16-33. SEM image of the iridocorneal angle of a horse.

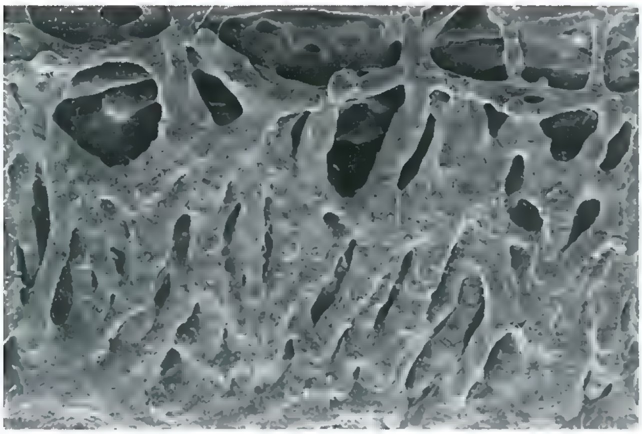


Fig. 16-34. SEM image of the ligamentum pectinatum at the iridocorneal angle of a horse.

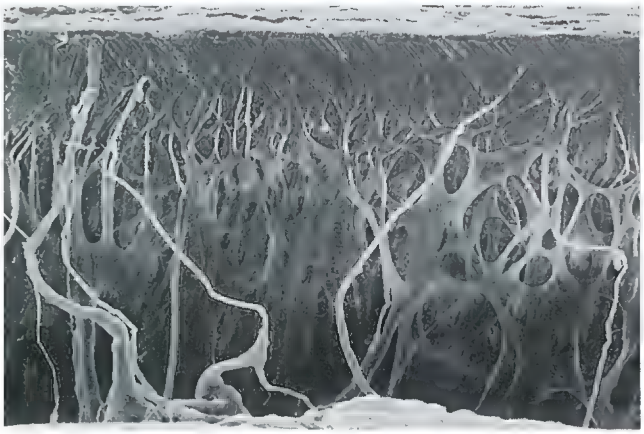


Fig. 16-35. SEM image of the ligamentum pectinatum at the iridocorneal angle of a cat.

body, the retina encloses the remainder (Fig. 16-2). The vitreous chamber is occupied by the vitreous body, a soft, clear gel, that conforms to the shape of its surroundings. It is mainly composed of the **vitreous humor,** a solution of mucopolysaccharides rich in hylaruronic acid (99% water, 1% solids). It is almost acellular, except for a few hyalocytes, that produce protein fibres. These fibres reinforce the structure of the vitreous and are essential to its gel characteristics. The cells are especially numerous towards the surface, where they condense to form the **membrana vitrea.** However, they do not provide sufficient rigidity to maintain the shape of the vitreous after its removal from the eye.

The **hyaloid canal** (canalis hyaloideus) traverses the vitreous from the posterior surface of the lens to the optic disc. It is the remnant of the **hyaloid artery,** a branch of the retinal arteries, which supply the lens during embryological develoment. This artery usually degenerates after birth and the lens is then nourished by diffusion. The hyaloid canal is present in the ox, pig and in carnivores.

While in the ox, sheep and pig the vitreous body is a relatively dense structure, in the horse it has a low optic density and in carnivores it has a dense core, but a low density in the periphery.

The eye is considered to consist of **several optical surfaces,** which together accurately focus images onto the retina. The optical components through which the light travels to reach the retina are the cornea, aqueous humor, lens and vitreous body. For proper image formation these components must remain transparent.

The **refractive power** of an optical component is determined by its **refractive index, thickness** and **surface curvature.** It is largely influenced by the difference in refractive indices between it and the surrounding media. This difference is greatest at the air-cornea interface; thus the cornea is the most powerful refractive component of the eye. While the lens has the highest refractive index, it is surrounded by media with similar indices. The lens is the only refractive component, that is capable of changing its refractive index.

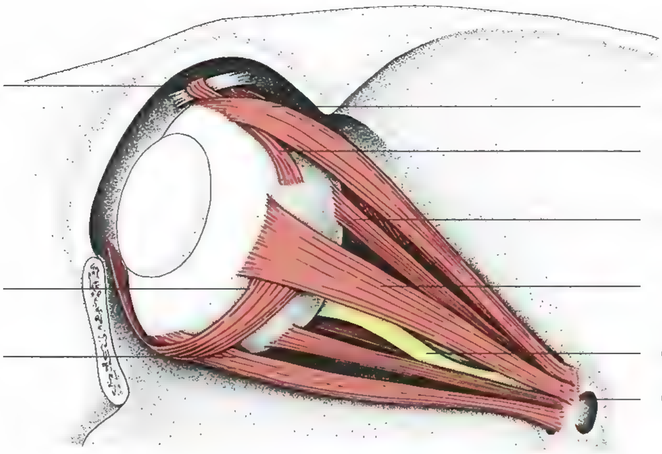


Fig. 16-36. Schematic illustration of the orbit and extrinsic ocular muscles of the dog.

Adnexa of the eye (organa oculi accessoria)

The adnexa of the eye include the following accessory structures:

- Orbit (Orbita) with the orbital fat body (corpus adiposum orbitae),
- Orbital fasciae,
- Extrinsic muscles of the eyeball (musculi externi bulbi oculi),
- Lacrimal apparatus (apparatus lacrimalis) and
- Vessels and nerves.

Orbit (orbita)

The orbit is the cone-shaped cavity on the lateral surface of the skull that contains the eyeball and most of the ocular adnexa (Fig. 16-36). It is continuous with the temporal and the pterygopalatine fossa caudally. It is deliminated, externally by a bony ring, which is open laterally in carnivores and in the pig, where the ring is completed by the orbital ligament (for a more detailed description see chapter 1).

The **orbit** is lined by a connective tissue layer, the **periorbita,** which is derived from the **periosteum** (Fig. 16-26). The orbital fat pad cushions the contents of the orbit and, being easily deformed, allows rotation and retraction of the eyeball. Embedded in the orbital fat pad are fasciae, muscles, vessels and nerves. Extraorbital fat pads fill the temporal fossa. In very thin animals these fat pads are reduced and the eyes sink within the orbit, giving the face a suffering appearance.

The position of the orbits are species specific: in the dog and cat they are set forward, while in herbivores they are more lateral.

Fasciae and extrinsic muscles of the eyeball

The following fascial layers surround the eyeball, the optic nerve and the muscles of the eyeball:

- muscular fasciae (fasciae musculares) surround the muscles of the eyeball and extend into the eyelids,
- bulbar sheath (vagina bulbi) covers the eyeball and is separated from the sclera by the episcleral space.

It facilitates the movement of the eyeball against the retrobulbar fat. It also **ensheaths the optic nerve** (vagina n. optici) and the retractor muscles of the eyeball.

The muscles important to the function of the eye constitute three groups: the **intrinsic,** the **extrinsic** and the **palpebral muscles.** The intrinsic muscles regulate the pupillary diameter and the shape of the lens; they are described earlier in this chapter. The palpebral muscle group includes the muscles of the lid and the muscles of the head, that regulate the shape and position of the palpebral fissure and are described later.

The extrinsic muscles of the eyeball are concerned with the movement of the eyeball. This group includes the:

- dorsal, ventral, medial and lateral straight muscles,
- dorsal and ventral oblique muscles,
- retractor muscle of the eyeball and
- levator muscle of the upper eyelid.

The **four straight muscles** (mm. rectus dorsalis, ventralis, medialis et lateralis) are named after the position of their insertion on the globe. They are the deepest muscles of this group and originate in close proximity to one another around the margin of the optic foramen and the orbital fissure. They are flat muscles that pass to the respective aspects of the eyeball, where they insert to the sclera close to the cornea.

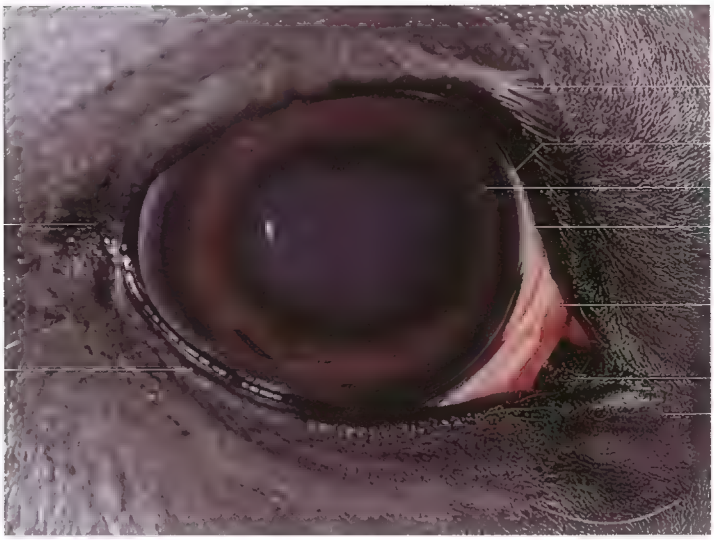


Fig. 16-37. Right eye with eyelids of a horse (courtesy of Prof. Dr. H. Gerhards, Munich).

The **ventral oblique muscle** (m. obliquus ventralis) of the eyeball arises from a small depression (foramen muscularis) in the palatine bone. It courses dorsolaterally to insert on the temporal aspect of the eyeball below the insertion of the lateral rectus muscle.

The **dorsal oblique muscle** (m. obliquus dorsalis) arises close to the ethmoidal foramen and runs anteriorly between the dorsal and medial rectus muscles. It is deflected around the trochlea to insert on the dorsotemporal surface of the eyeball deep to the insertion of the dorsal rectus muscle. The trochlea is a small, oval plate of hyaline cartilage in the periorbita that is firmly attached to medial orbital wall by ligaments.

The **retractor muscle of the eyeball** (m. retracor bulbi) arises close to the optic foramen and forms a nearly complete muscular cone around the optic nerve. It inserts posterior to the equator with numerous broad and thin fascicles. It is not present in man.

The **extrinsic muscles** of the eyeball rotate the globe around three perpendicular axes. The complex movements of the eye require the fine coordination of all of these muscles and they never act alone. Principally, the dorsal and ventral straight muscles rotate the globe around a medial to lateral axis, the medial and lateral straight muscles around a dorso-ventral axis and the oblique muscles rotate the eyeball around the axis of the eyeball. In addition the eyeball can be retracted into the orbit along the optic axis by the retractor muscle of the eyeball.

The **extrinsic muscles** of the eyeball are mainly innervated by the **oculomotor nerve (III),** with the exception of the dorsal oblique muscle, that is innervated by the trochlear (IV) nerve and the lateral straight and the lateral part of the retractor muscle of the eyeball, that are innervated by the abducent nerve (VI).

Eyelids (palpebrae)

The eyelids are musculofibrous folds that can be drawn over the anterior surface of the eyeball to occlude light, protect the cornea and assist in keeping the cornea moist.

There are three eyelids in the domestic mammals: the **upper lid** (palpebra superior), **lower lid** (palpebra inferior) and the **third eyelid** (palpebra tertia, membrana nictitans) (Fig. 16-37 and 38).

The opening between the upper and lower **lids** (rima palpebralis) is variable in size and is controlled by the palpebral muscles. The **free margins** (margo palpebrae) of the upper and lower lid meet at the **nasal** and **temporal angles** (canthi) of the eye (angulus oculi temporalis et nasalis).

A mucosal prominence, the **lacrimal caruncle** (caruncula lacrimalis), is present in the nasal angle of the eye (Fig. 16-40). Small fine hairs project from the caruncle and, in the dog, a pea-sized lacrimal gland lies beneath it. The lacrimal puncta, through which the tear film drains, open onto the lid margins close to the nasal angle.

The eyelids consist of three layers: skin, a middle musculofibrous layer and the **mucous membrane** (the palpebral conjunctiva). The skin of the face continues onto the **anterior surface of the lids** (facies anterior palpebrarum) with little alteration. It is covered with hairs and includes glandular structures. Long hairs (cilia) project from the upper lid margins.

The eyelids contain **several glands:**

Sebaceous glands open into the follicles of the cilia. **Ciliary glands** are coiled, tubular, apocrine sweat glands that secrete into hair follicles, sebaceous glands secrete directly onto the lid margin. **Tarsal glands** are specially modified sebaceous glands that are present in both eyelids. They produce the oily superficial layer of the tear film.

The **middle layer of the eyelid** is formed by the fibres of the lid fascia and the orbicular muscle of the eyeball. The orbicular muscle of the eyeball is a striated muscle, the fibres of

Fig. 16-38. Histological section of the upper eyelid of a calf.

Fig. 16-39. Histological section of the third eyelid of a horse.

which radiate into the eyelids, where they form a circular arrangement and join the tarsal plate and the smooth tarsal muscle of the upper lid. Toward the free margin these structures are succeeded by the tarsal plate, a fibrous condensation, that stabilises the free margin of the lid. The levator muscle of the upper eyelid (m. orbicularis oculi) extends from the ethmoidal foramen to the upper lid of the eye.

The **posterior surface of the eyelids** are lined by a mucous membrane, the **palpebral conjunctiva.** At the level of the orbital rim the conjunctiva reflects onto the surface of the globe to become the **bulbar conjunctiva.** The point of reflection is the **conjunctival fornix.** Multiple small folds are formed in the fornix, when the eye is open.

The **conjunctival sac** is the potential space between the lower lid and the eyeball that normally contains mucus and tears. The conjunctiva consists of a stratified epithelium with goblet cells in its palpebral part. It overlies a loose connective tissue stroma, that is rich in lymphatic tissue. The bulbar conjunctiva is thin and continuous with the anterior epithelium of the cornea.

The **third eyelid** (palpebra tertia, membrana nictitans) or **semilunar fold of the conjunctiva** (plica semilunaris conjunctivae) is a dorsoventrally orientated conjunctival fold, that extends from the nasal canthus between the lacrimal caruncle and the eyeball (Fig. 16-39). It is supported by a T-shaped piece of cartilage, which consists of elastic cartilage in the horse, pig and the cat and of hyaline cartilage in the dog and in ruminants. Numerous **lymphatic nodules** (noduli lymphatici conjunctivales) are found within the third eyelid, which are enlarged in chronically infected eyes and may cause further irritation.

The base of the cartilage is surrounded by the **superficial gland of the third eyelid** (glandula palpebrae tertiae superficialis). It is a mixed seromucous gland in the ox, sheep and dog, serous in the cat and horse and mucoid in the pig. It contributes considerably to the production of the precorneal tear film. Pigs also have a **second, deeper gland** (glandula palpebrae tertiae profunda).

Lacrimal apparatus (apparatus lacrimalis)

The precorneal tear film protects the eye by washing away foreign material and is essential in maintaining the transparency of the cornea. Insufficient tear production results in opacification.

The **tear film** consists of a superficial, oily layer, a central aqueous layer and a thin glycoprotein layer covering the cornea. The superficial oily layer is produced by the tarsal glands and provides lubrication, prevents overflow of tears from the lid margin and retards evaporation of the underlying aqueous layer. The aqueous layer is the major component of the tear film and is produced by the lacrimal gland and the gland of the third eyelid. It moistens and nourishes the cornea. The innermost layer is produced by the goblet cells of the conjunctival epithelium and assists in adherence of the precorneal film to the corneal surface.

The lacrimal apparatus includes the structures that are responsible for the production, dispersal and disposal of the tears (Fig. 16-40):

- Lacrimal gland (glandula lacrimalis),
- Glands of the third eyelid (glandulae palpebrae tertiae),
- Lacrimal canaliculi (canaliculi lacrimales),
- Lacrimal sac (saccus lacrimalis) and
- Nasolacrimal duct (ductus nasolacrimalis).

The **lacrimal gland** is a tubulo-alveolar gland that is situated between the eyeball and the dorsotemporal wall of the orbit. Its secretion is serous in all domestic mammals other than the pig in which it is mucoid. In carnivores, it lies beneath the orbital ligament, whereas in the horse it occupies the lacrimal fossa.

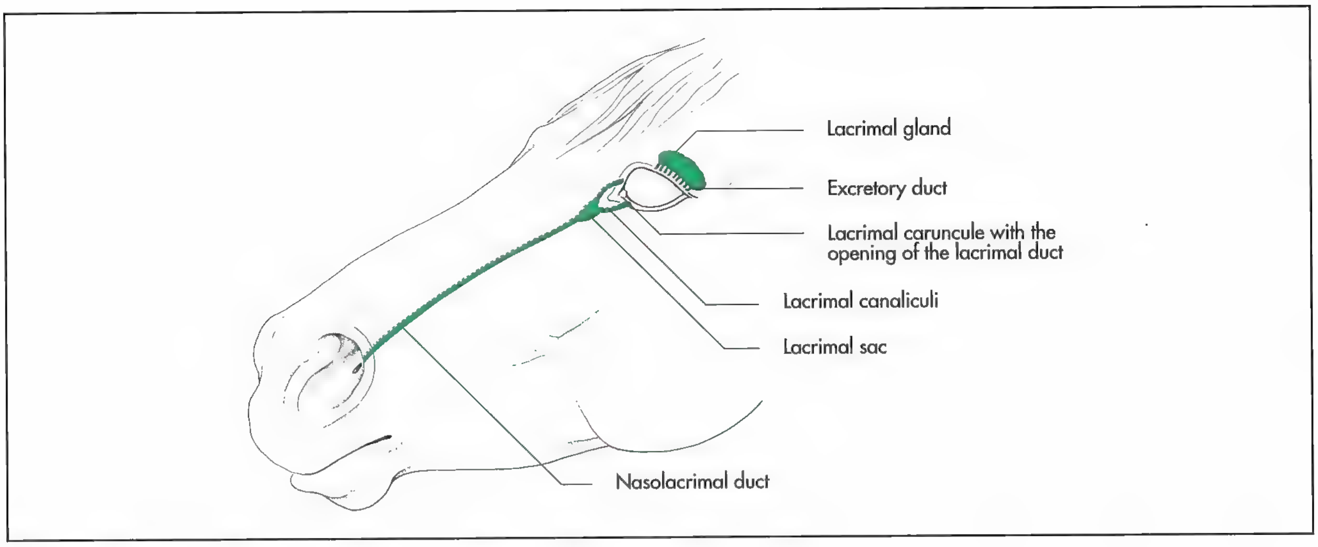


Fig. 16-40. Schematic illustration of the lacrimal apparatus of the horse.

Its secretion is drained by many **minute ducts** (ductuli excretorii), that open at the dorsotemporal margin of the upper lid into the conjunctival sac (Fig. 16-40). Blinking movements distributes the tear fluid over the anterior surface of the eye.

The drainage of lacrimal secretions, begins with the **lacrimal puncta** (puncta lacrimalia), small slits, that are located close to the lacrimal caruncle at the nasal angle of the eye. Each lacrimal punctum leads to a short narrow canaliculus, which opens in the dilated lacrimal sac. The lacrimal sac marks the beginning of the nasolacrimal duct, which occupies a funnel-shaped fossa within the lacrimal bone. The walls of the lacrimal sac contain large amounts of lymphoreticular tissue.

The **nasolacrimal duct** is a soft tissue tube, that passes through the lacrimal bone and the maxilla. Rostrally it is emerges from its boney canal and continues deep to the nasal mucosa on the nasal aspect of the maxilla. It ends by opening into the **nares.**

Lacrimal drainage varies among the species and between individuals. In the dog the lacrimal puncta are relatively large and are easily cannulated. Rostrally the nasolacrimal duct passes medial to the ventral lateral nasal cartilage and ends by opening onto the ventrolateral floor of the nasal vestibule below the alar fold. The rostral opening cannot be visualised without a speculum. In about a third of dogs, the duct opens in the ventral nasal meatus.

In the horse the **lacrimal puncta** are relatively small. The lacrimal sac lies beneath the **lacrimal caruncle,** covered by the palpebral portion of the orbicularis oculi muscle. The nasolacrimal duct passes rostrally within the lacrimal sulcus of the maxilla to the infraorbital foramen. Its narrow middle part continues in the mucosa of the middle nasal meatus. The nasolacrimal duct opens on the floor of the **nares,** near the **mucocutaneous junction.** Occasionally the duct has more than one opening and in some horses blind-ending openings may be present. The nasal opening can be conveniently used for examining and flushing the duct.

Blood supply and innervation

Blood vessels of the eye

The principal blood supply to the eyeball is provided by the **external ophthalmic artery** (a. ophthalmica externa), a branch of the **maxillary artery.**

The external ophthalmic artery enters the eyeball at the area cribrosa, where it detaches the short **posterior ciliary arteries** (aa. ciliares posteriores breves). These vessels form the vascular circle of the optic nerve and constitute the parent vessel to the **central retinal artery.** They also form the episcleral blood vessels and the **long posterior ciliary arteries** (aa. ciliares posteriores longae), which pass through the sclera near the equator to join the corresponding vein in forming an elaborate plexus within the choroid. These are complemented anteriorly by the **anterior ciliary arteries** (aa. ciliares anteriores), which penetrate the sclera near the limbus and supply the anterior portion of the choroid, the ciliary body and the iris. These arteries anastomose to form the **major vascular circle** of the iris from, which numerous branches pass to the anterior structures of the eyeball, including **posterior and anterior conjunctival branches** (aa. conjunctivales posteriores and anteriores) to the conjunctiva.

Veins are in general parallel to the arteries. Venous return from the choroid is achieved by the four **vorticose veins** (vv. vorticosae) that drain into the **external ophthalmic vein.** The scleral venous plexus, through which the aqueous humor drains, opens into the anterior ciliary veins (vv. ciliares anteriores).

Arterioles and venules merge from the optic disc and spread out in various patterns to nourish and drain the retina. For clinical purposes it is important to know that the blood vessels of the optic fundus are characteristic for each species and changes with advancing age in the individual.

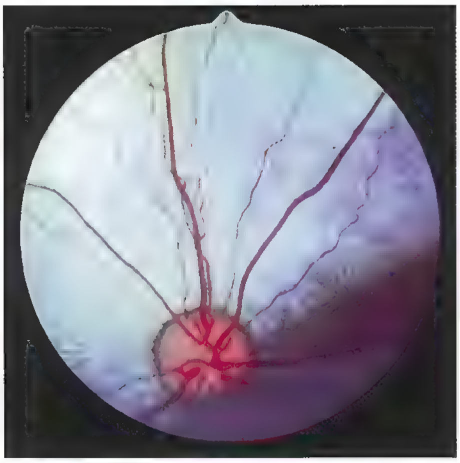


Fig. 16-41. Ocular fundus with branches of the central retinal artery and vein in a 6 week old wire haired dachshound. Azur-blue lightening of the tapetum lucidum and venous arch around the optic disc (courtesy of Prof. Dr. R. Köstlin, Munich).

Fig. 16-42. Ocular fundus with branches of the central retinal artery and vein in a 3.5 year old wire haired dachshound. The tapetum lucidum is poorly pigmented and appears light blue, the surrounding are is heavily pigmented and dark blue. The venous trunks arch around the optic disc (courtesy of Prof. Dr. R. Köstlin, Munich).

Fig. 16-43. Ocular fundus with branches of the central retinal artery and vein in a husky with a pigment defect (courtesy of Prof. Dr. R. Köstlin, Munich).

Fig. 16-44. Ocular fundus with branches of the central retinal artery and vein in a toy poodle. The tapetum lucidum is extensive and the pigmented area forms a ring around the optic disc (courtesy of Prof. Dr. R. Köstlin, Munich).

Innervation of the eye and its adnexa

The eye and its adnexa are innervated by cranial nerves II, III, IV, V, VI and VII (see chapter 14, "Nervous system")

The **optic nerve** (n. opticus) or cranial nerve II is a central nervous system tract, which is sensory only and is concerned with vision.

The **oculomotor** (n. oculomotorius, III), the **trochlear** (n. trochlearis, IV) and the **abducent nerve** (n. abducens, VI) control movement of the eyeball by innervating its extrinsic muscles. The **facial nerve** (n. facialis, VII) is motor to the orbicularis oculi muscle and also provides parasympathetic fibres for the petrosus major nerve, that innervates the lacrimal glands.

The eye is richly supplied by branches of the **trigeminal nerve** (n. trigeminus, V). The **ophthalmic** nerve is the principal sensory innervation of the eye and orbit: The **frontal nerve** innervates the upper eyelid, the **lacrimal** nerve, the skin and conjunctiva at the temporal canthus, the **infratrochlear** nerve, the nasal canthus of the eye and the **nasociliary nerve** the cornea and the choroid. The **zygomatic branch** of the maxillary nerve is sensor to the lower eyelid. The branches of the trigeminal nerve are responsible for the afferent pathways of the corneal and palpebral reflexes.

Parasympathetic presynaptic nerve fibres innervate the **ciliary ganglion** with the occulomotor nerve. There they synapse and their postsynaptic fibres form the **short ciliary nerves** (nn. ciliares breves). They also receive **sympathetic** and **sensory fibres** and are responsible for the autonomic regulation of the pupillary reflex and accommodation of the lens. Parasympathetic stimulus causes contraction of the pupillary sphincter muscle, sympathetic stimulus contraction of the pupillary dilator muscle.

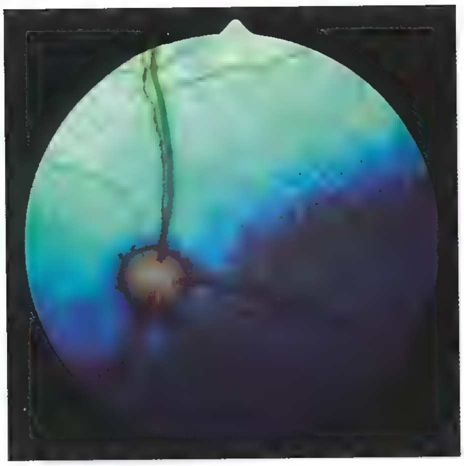


Fig. 16-45. Ocular fundus of a juvenile cat with strongly reflecting tapetum lucidum, dense fundus and distinct optical disc (courtesy of Prof. Dr. R. Köstlin, Munich).

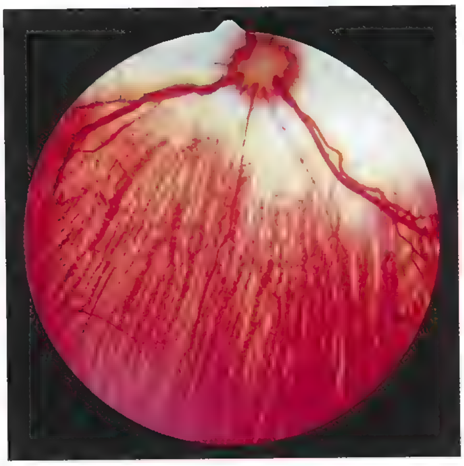


Fig. 16-46. Ocular fundus of a one year old cat with pigment defect, showing a transparent sklera (courtesy of Prof. Dr. R. Köstlin, Munich).

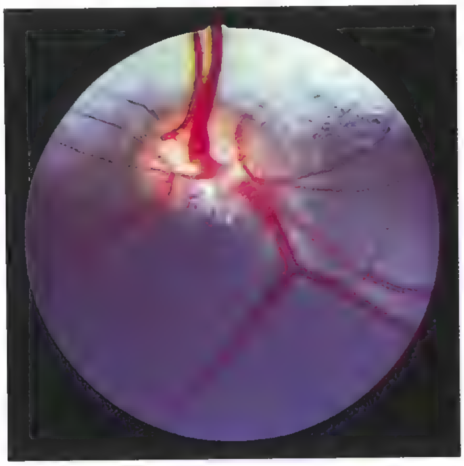


Fig. 16-47. Ocular fundus of a merion sheep, (courtesy of Prof. Dr. R. Köstlin, Munich).

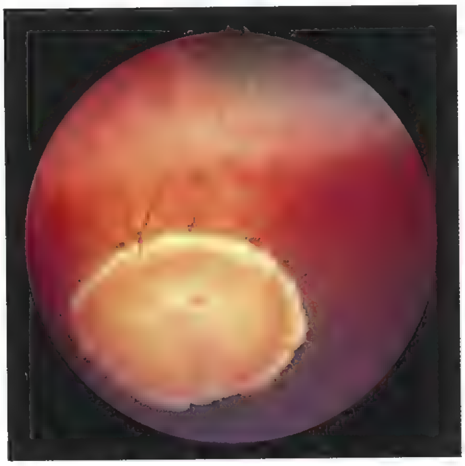


Abb. 16-48. Ocular fundus of a horse with distinc optic disc and normal fundus albinism (courtesy of Prof. Dr. H. Gerhards, Munich).

Visual pathways and optic reflexes

The visual pathways comprise **central** and **peripheral segments.** The peripheral part includes the retinal neurons, the optic nerve, the optic chiasm, the optic tracts, the thalamus and the lateral geniculate bodies. The **central part** consists of the optic radiation, the rostral colliculi, the geniculo-occipital tract and the optic area of the cerebral cortex.

The retina contains the **receptors for visual information.** The received information is then conveyed to the brain by the **optic nerve.** The optic nerve of each eye converge to meet in the optic chiasm on the ventral surface of the brain, where part of the **fibres decussate** (Fig. 14-29).

The proportion of fibres that are exchanged with the opposing optic nerve is correlates with the degree of binocular vision enjoyed by the species. After the optic chiasm, the fibres continue as the **optic tract** (tractus opticus), which terminates in the **lateral geniculate nucleus** and in the **optic thalamus.** From the thalamus, second stage neurons project, via the **optic radiation** (radiatio optica) of the **internal capsule,** on the visual cortex located within the **occipital lobe of each hemisphere.** This is the area of **conscious visual perception.**

Some fibres leave the optic tract to terminate in the rostral colliculi of the midbrain, in nuclei of the **reticular formation** and the **caudate nucleus.** These are responsible for optic reflexes, such as the pupillary reflex and accommodation.

Clinical terms related to the eye:
Conjunctivitis, corneal ulcer, retinopathy, uveitis, keratitis, glaucoma, cataract.

17 Vestibulocochlear organ (organum vestibulocochleare)

H.-G. Liebich and H.E. König

The ear is appropriately termed the vestibulocochlear organ since it includes both, the organs of balance and of hearing. Sound waves provide mechanic stimuli, which are received and transformed into electrical signals by the cochlea, while neuroreceptors within the vestibular organ provide the animal with a perception of position and movement with respect to gravity. The receptors of both organs are part of the inner ear, which is located in the petrous temporal bone. The two organs are linked anatomically and functionally by the vestibulocochlear nerve.

The ear has three subdivisions (Fig. 17-1):

- External ear (auris externa),
- Middle ear (auris media),
- Internal ear (auris interna).

The organ of balance (vestibular system) is restricted to the internal ear.

External ear (auris externa)

The external ear consists of the:

- Auricle (auricula) with the auricular cartilage (cartilago auriculae), the scutiform cartilage and the auricular muscles (mm. auriculares),
- External acoustic meatus (meatus acusticus externus),
- Tympanic membrane (membrana tympani).

The external ear helps to direct and transmit sound waves into the middle ear.

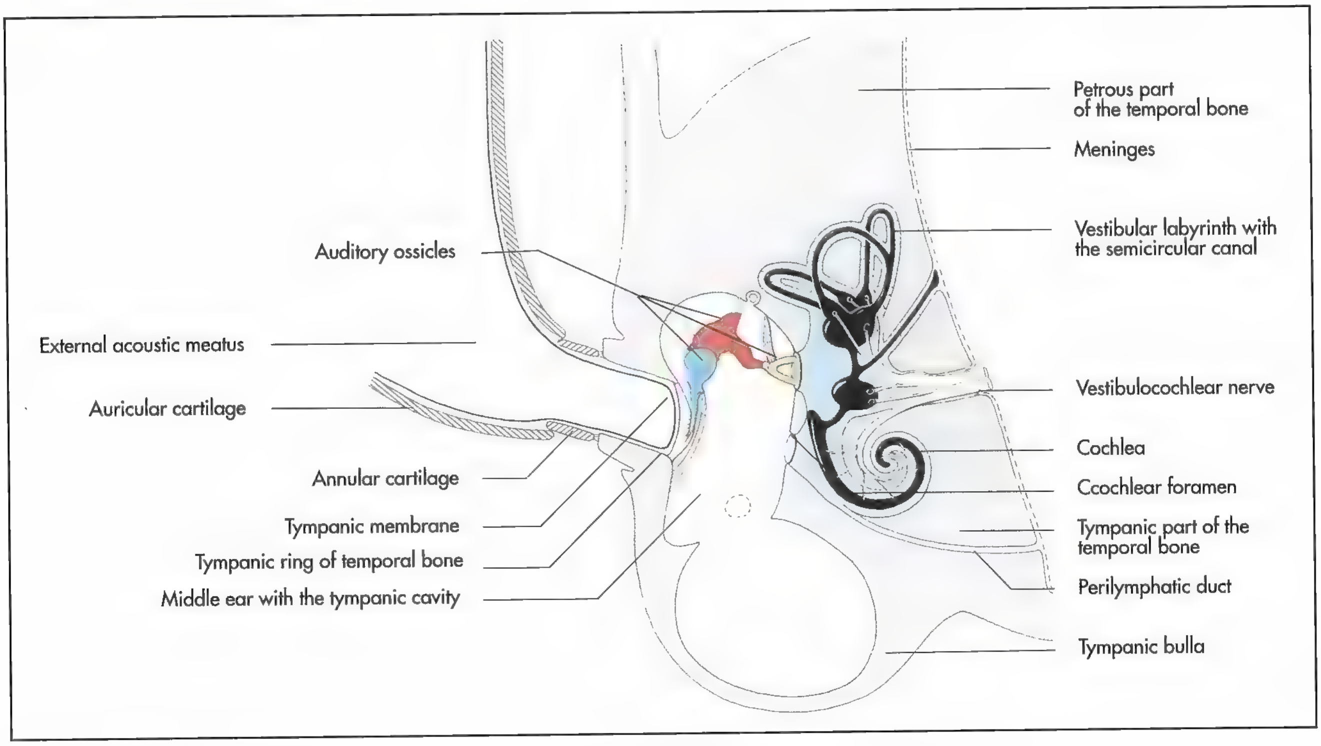


Fig. 17-1. Schematic illustration of the external acoustic meatus, the middle and internal ear of the dog.

Fig. 17-2. Auricle of a cat (König, 1992).

Fig. 17-3. Auricle of a dog (courtesy of Dr. R. Macher, Vienna).

Auricle (auricula)

The **external ear** (also called auricle or pinna) of the domestic mammals varies greatly in size and shape between species and breeds. The breed specific variations are especially well-pronounced in dogs (Table 17-1). In most animals the external ear is highly mobile and is important for the communication between individuals (Fig. 17-2 and 3).

The **auricle** is shaped like a funnel and serves as a sound gathering structure. It is moved by the auricular muscles to localize and collect sound. Several auricular muscles arise from the scutiform cartilage, a small cartilaginous plate on the rostromedial aspect of the auricle, others arise from neighbouring parts of the skull.

The **auricular muscles** are arranged around the auricle and insert upon it. They rotate the external ear and move it upward and downward. The muscles consists of several layers and numerous slips, that may differ in size or insertion not only between species and breed, but also from one individual to another. Like the other mimetic muscles they are innervated by the intermediofacial nerve.

The auricle is shaped like a funnel, opening distally and narrows to form a tube proximally. The size and shape of the auricle is determined by the auricular cartilage, which is covered by skin. The hairs are thin and sparse on the concave surface, apart from a few **long hairs** (tragi) protecting the entrance to the external acoustic meatus. The convex surface is covered by normal fur and, especially in dogs with pendulous ears, it has dense long hairs. Following human anatomical nomenclature, the following features can be distinguished (Fig. 17-2 and 3):

- Tip of the ear (apex auriculae),
- Rostral and caudal margins,
- Convex surface (dorsum auriculae),
- Concave surface with
- Scapha,
- Concha and
- Species-specific cartilagenous structures: crus of helix, anthelix, tragus, antitragus.

The **concave surface of the auricle** is divided into the **proximal concha** (concha auriculae), or **conchal cavity,** from the more distally located and flattened scapha. A separate cartilagenous band, the **annular cartilage** (cartilago annularis) fits within the base of the conchal tube and overlaps and attaches to the **osseous external acoustic meatus** (Fig. 17-2 and 3). In the cat and dog, the caudal margin presents the **cutaneous marginal pouch** (saccus cutaneus marginalis).

Tab. 17-1. Breed specific ear forms.

Short ercet ear:	Spitz, Northern sledge dog	Rose ear with the ear tip lying close to the head:	Greyhounds
Long erect ear:	German shepard	Lop-eared:	Great dane, a few types of Gun dogs
Bat ear:	French bulldog	Lop-eared (long):	Bloodhounds, a few Tracker dogs
Drop ear:	Foxterrier, Collie		

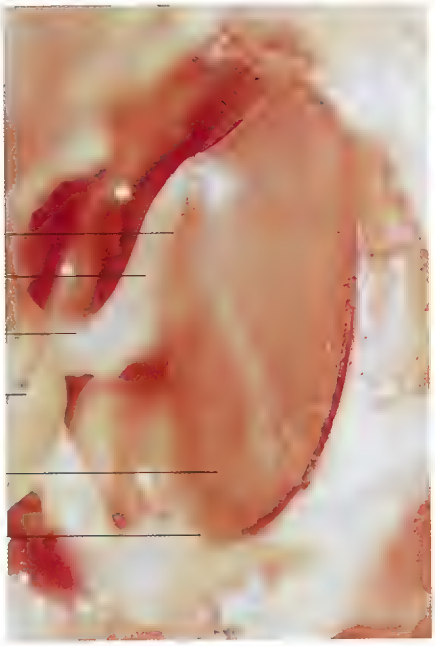


Fig. 17-4. Tympanic membrane of a cat with manubrium of the malleus, internal aspect (Hartmann, 1992).

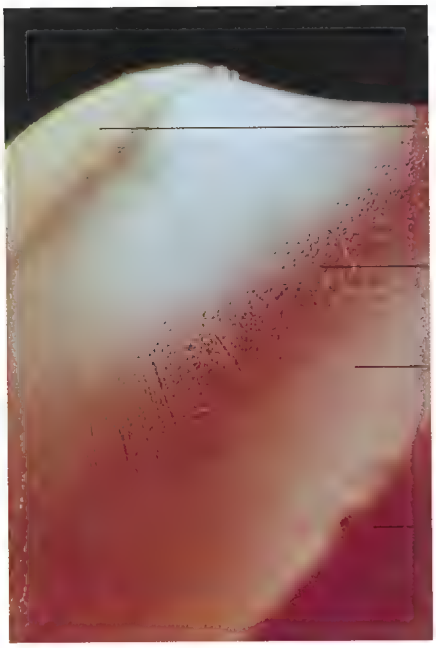


Fig. 17-5. Attachment of the malleus to the tympanic membrane of a cat (umbo membranae tympani) (Hartmann, 1992).

External acoustic meatus (meatus acusticus externus)

The external acoustic meatus has a **distal cartilagenous part** and a **proximal osseous part.** It begins with the narrowed part of the auricular cartilage and ends at the eardrum.

In carnivores and pigs the cartilaginous part is relatively long and curved with its initial part directed downward, followed by a horizontal part, that is directed medially.

The osseous part is relatively short and is attached to the basal portion of the concha by the annular cartilage. This arrangement of a separate joining ring between the auricle and the external acoustic meatus gives the external ear added flexibility. The **external acoustic meatus** is lined with a stratified, squamous epithelium, which contains sebaceous and tubular ceruminous glands, which secrete **earwax** (cerumen). In the horse and in ruminants, these glands are located within the cartilagenous part of the external acoustic meatus. In carnivores, the glands are located along the whole of the external acoustic meatus.

Tympanic membrane (membrana tympani)

The tympanic membrane, or **eardrum,** separates the middle ear from the external acoustic meatus (Fig. 17-1, 4 and 5). It transmits sound waves onto the auditory ossicles of the middle ear. It is a thin, semi-transparent sheet that is suspended within the **tympanic ring** (anulus tympanicus). The tympanic ring is interrupted dorsally by a **notch,** which is bridged by soft tissue.

The part of the tympanic membrane that attaches to the tympanic ring is **tense** (pars tensa), while that part that covers the notch of the tympanic ring is flaccid (pars flaccida). The tympanic membrane is composed of three layers:

- Outer stratified squamous epidermis (stratum cutaneum),
- Central fibrous connective tissue layer (stratum proprium),
- Inner mucosa (stratum mucosum).

Its **outer surface** is covered with an epithelium continuous with that of the external acoustic meatus and its medial surface by the mucosa lining the tympanic cavity. The unpigmented outer layer does not contain any hairs or glands. The **central layer** is arranged in outer radial and inner circular layers, that continue into the fibrocartilageneous ring that attaches the tympanic membrane to the osseous tympanic ring (Fig. 17-1, 4, 7, 10, 14 and 16).

The **inner mucosa** consists of a single-layered squamous epithelium, which extends onto the surface of the malleus, which in turn is firmly attached to the connective tissue fibres. The site of attachment is called the umbo of the tympanic membrane.

The **external aspect** of the tympanic membrane is depressed opposite adjacent to the distal **end of the malleus,** owing to the traction exerted by it. A light coloured **streak** (stria mallearis) may be seen at that site. The handle of the malleus is embedded within the tympanic membrane, while the head articulates with the body of the adjacent auditory ossicle, the **incus.** Incoming sound waves are transformed into mechanical impulses by the tympanic membrane and conveyed to the inner ear by the auditory ossicles (Fig. 17-13). The tympanic membrane is slanted and oval in shape in the dog. In the cat it is pointed, in the pig circular and in the horse and ox oval. The tympanic membrane is generously vascularised and **innervated** by **sensory nerve fibres.**

Fig. 17-6. Transverse section of the head of a cat at the level of the ear (König, 1992).

Fig. 17-7. Transverse section of the skull of a dog, tympanic cavity opened.

Middle ear (auris media)

The middle ear comprises (Fig. 17-1, 6, 10 to 13):

- Tympanic cavity (cavum tympani),
- Auditory ossicles (ossicula auditus),
- Auditory tube (tuba auditiva, eustachian tube).

In the horse, the auditory tube forms a large diverticulum, the **guttural pouch** (diverticulum tubae auditivae) (Fig. 17-20 and 21).

Tympanic cavity (cavum tympani)

The tympanic cavity is housed within the petrous temporal bone. It can be divided into dorsal, middle and ventral parts.

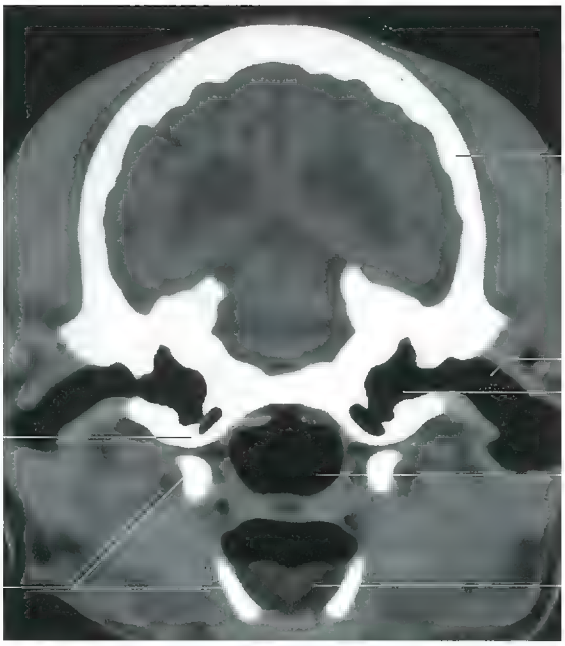


Fig. 17-8. Computed tomogram of the vestibulocochlear organ of a cat (courtesy of Dr. A. Probst, Vienna).

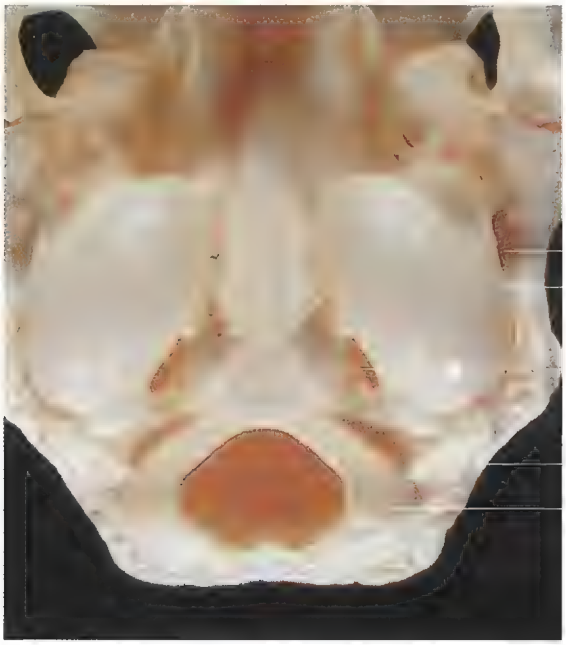


Fig. 17-9. External osseous parts of the vestibulocochlear organ of a cat, ventral aspect.

The dorsal part, the **epitympanicum,** contains the auricular ossicle. The middle part, or **mesotympanicum,** includes the tympanic membrane in its lateral wall and opens rostrally into the nasopharynx via the auditory tube. The ventral **hypotympanicum,** or **tympanic bulla** (bulla tympanica), is an enlarged bulbous expansion of the temporal bone, that is subdivided into numerous cells area in some species (Fig. 17-7, 10 and 13). The tympanic bulla forms the floor and a large part of the lateral walls of the tympanic cavity (for a more detailed description see chapter 1). The lateral wall of the tympanic cavity incorporates the tympanic membrane, the medial wall contains two windows.

The **oval vestibular window** (fenestra vestibuli) is located rostrodorsally and is occupied by the base of the stapes and connects the tympanic cavity with the internal ear. The **cochlear window** (foramen cochleae), situated more caudally, is

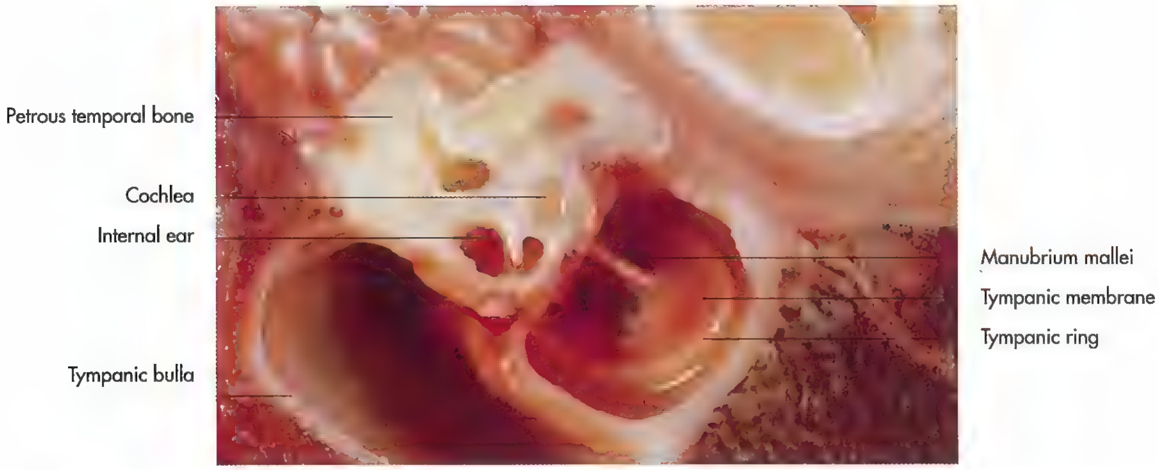


Fig. 17-10. Transverse section of the middle and internal ear of a dog showing the internal aspect of the tympanic membrane (courtesy of PD Dr. J. Maierl, Munich).

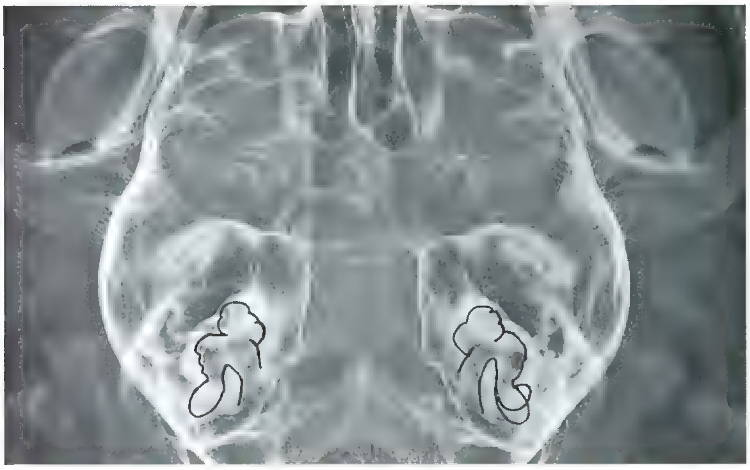


Fig. 17-11. Radiograph of the ears of a cat (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

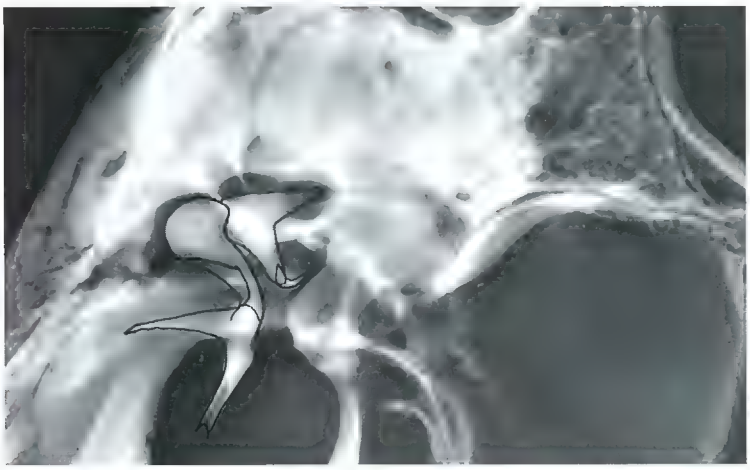


Fig. 17-12. Radiograph of the auricular ossicles (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

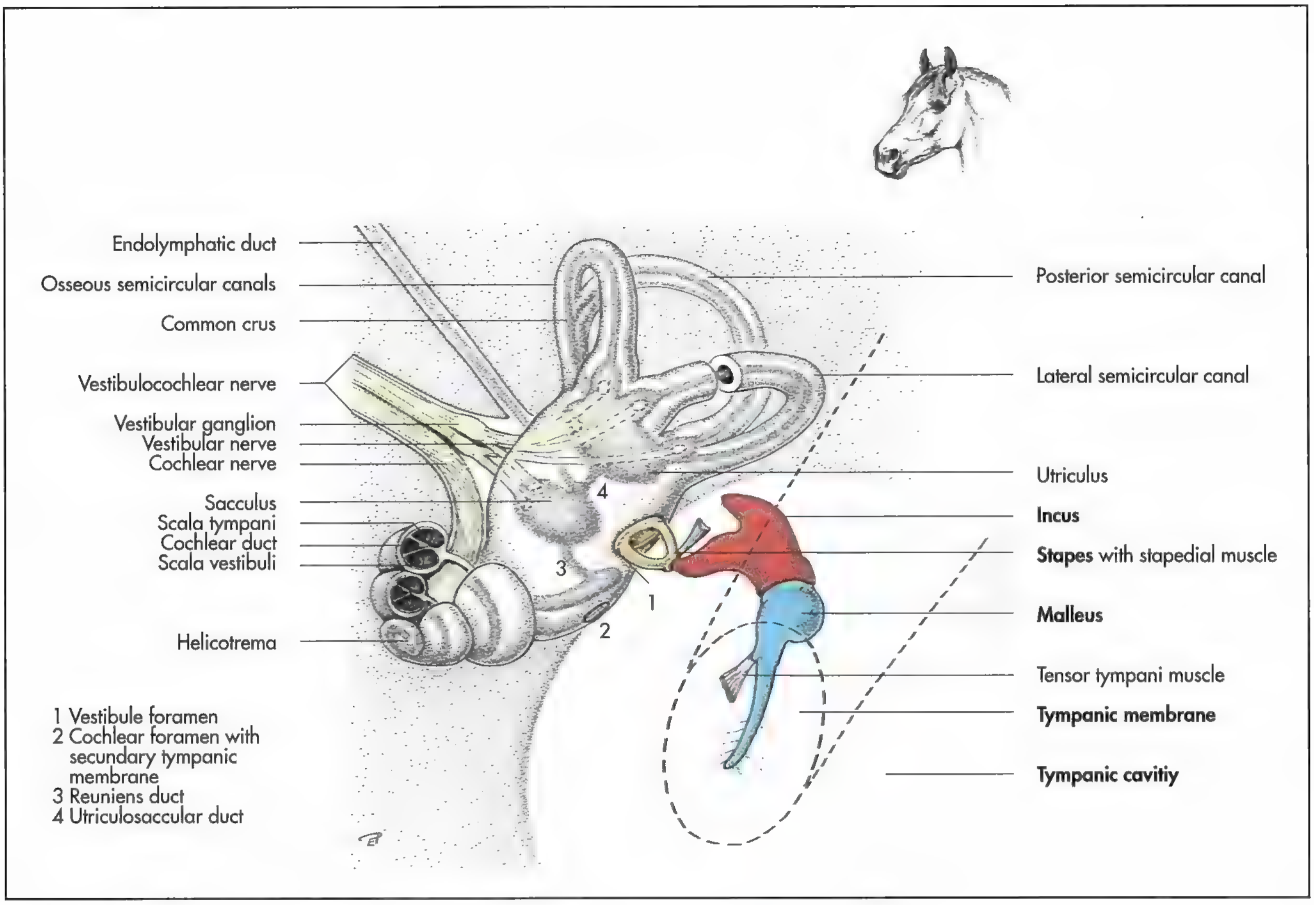


Fig. 17-13. Schematic illustration of the middle and internal ear of the horse (aspect like the insert).

round in shape and leads to the cavity of the cochlea. It is closed by the secondary tympanic membrane. The cochlea is located within a bony prominence, the **promontorium,** that protrudes from the medial wall of the tympanic cavity (Fig. 17-13 to 15).

The tympanic cavity is lined by a single-layered epithelium, which continues onto the auricular ossicles and the tympanic membrane. The underlying soft tissue has a rich vascular and nervous supply.

Auditory ossicles (ossicula auditus)

The transmission of vibrations from the tympanic membrane across the tympanic cavity to the inner ear is mediated by the three auditory ossicles:

- Malleus,
- Incus,
- Stapes.

They are small lamellar bones that are joined to each other by **syndesmoses** to form a chain, which extends from the tympanic membrane to the vestibular window.

In juvenile animals, there may be a small separate bone, the **lenticular bone** (os lenticulare), interposed between the incus and stapes, which fuses to the incus in later life. The most lateral of the auditory ossicles is the **malleus,** which consists of the **head, neck** and **manubrium.** The manubrium is embedded within the tympanic membrane (Fig. 17-4, 10, 13 and 17). It is joined to the head by the neck, which protrudes above the tympanic membrane, by a few millimetres. The saddle-shaped articular surface of the head of the malleus articulates with the body of the stapes.

The **incus** is divided into a body and short and long limbs (Fig. 17-13, 16 and 17). The long limb joins with the lenticular bone, which articulates with the head of the stapes (caput stapedis).

The **stapes** consists of a head, a neck, two limbs, a base and a muscular process (Fig. 17-13, 16 and 17). The base articulates with the fibrocartilagenous ring that surrounds the vestibular window.

Several **ligaments** and **mucosal folds** attach the auditory ossicles to the wall of the tympanic cavity. The manubrium of the malleus is attached to the tympanic ring by the **lateral ligament** of the malleus and to the wall of the epitympanicum by the **rostral ligament** of the malleus. The head of the malleus is attached to the dorsal wall of the epitympanicum by the **superficial ligament** of the malleus and is further stabilised by two mucosal folds, through which the chorda tympani passes.

Fig. 17-14. Transverse section of the tympanic part of the petrous bone of a horse.

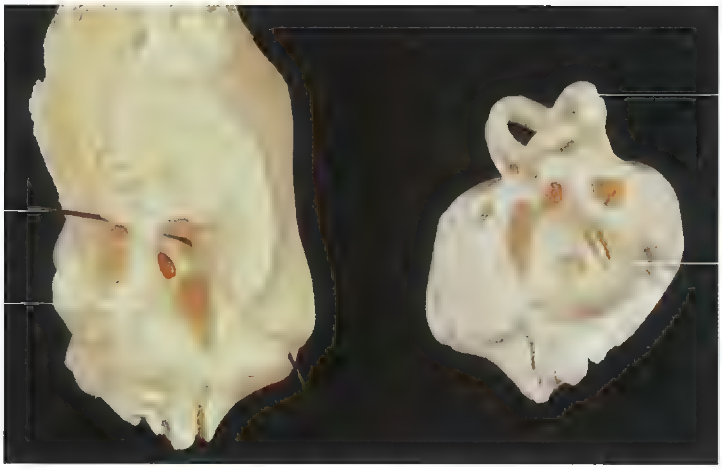


Fig. 17-15. Transverse section of the tympanic part of the petrous bone of an ox.

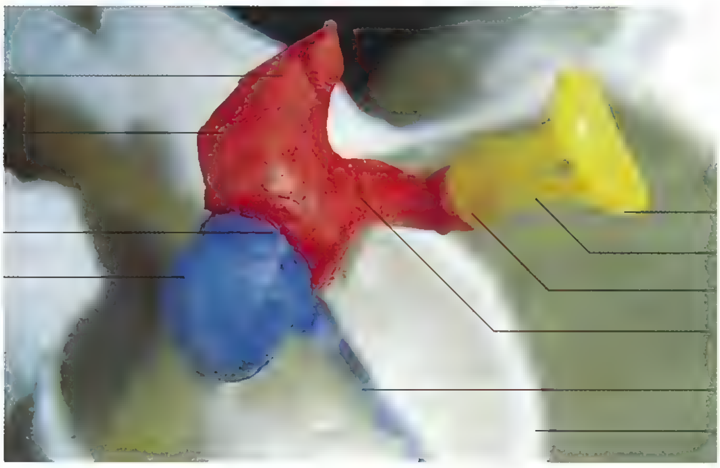


Fig. 17-16. Auditory ossicles of a horse.

Fig. 17-17. Radiograph of the malleus (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

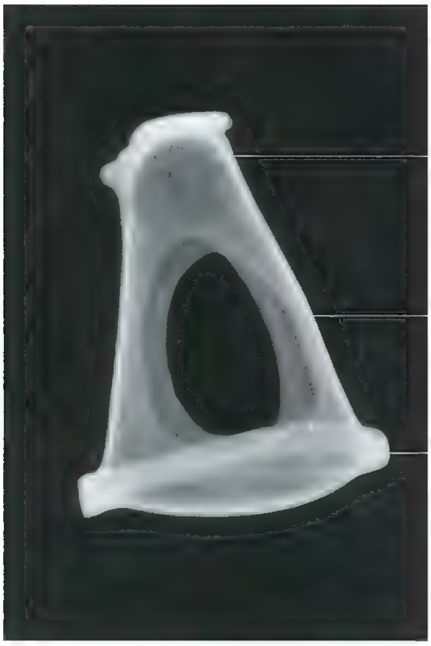


Fig. 17-18. Radiograph of the stapes (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

The **facial nerve** passes along the wall of the epitympanicum, and is seperated from the wall by mucosa in parts. The short limb of the incus is attached to the epitympanicum by the caudal ligament of the incus. An **annular ligament** (ligamentum anulare stapedis) attaches the base of the stapes to the vestibular window.

The **auditory ossicles** do not only transmit the vibrations of the tympanic membrane, but also magnify them by at least 20 times. This is essential to initiate waves in the endolymph of the inner ear. An important role in the enhancement mechanism is played by **two antagonistic muscles** associated with the ossicles: the tensor tympani and the stapedial muscle.

The **tensor tympani muscle** (m. tensor tympani) originates in the rostromedial part of the tympanic cavity and inserts to the manubrium of the malleus. Contraction of this muscle tensions the chain of auditory ossicles and the tympanic membrane, thus resulting in a higher sensitivity of the transmission system.

The **stapedial muscle** (m. stapedius) originates from a small fossa between the facial canal and the wall of the tympanic cavity and inserts to the head of the stapes. Contraction of the stapedial moves the base of the stapes away from the vestibular window, thus having an attenuating effect on transmission. The tensor tympani muscle is innervated by the pterygoid nerve, a branch of the mandibular nerve, the stapedial muscle is innervated by the facial nerve.

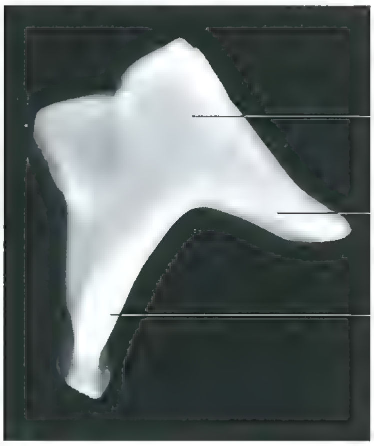


Fig. 17-19. Radiograph of the incus (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

Auditory tube (tuba auditiva, eustachian tube)

The auditory tube is a narrow, slit-like tube that connects the tympanic cavity with the nasopharynx. The tube is bordered by a ventrally open trough, which is osseous close to the **tympanic cavity** (pars ossea) and becomes cartilaginous towards the **pharynx** (pars cartilagenea tubae auditivae). Both parts are lined by ciliated epithelium, which contains goblet cells with an underlying collagenous-elastic soft tissue, rich in lymphoreticular cells. The tympanic cavity marks the opening into the **auditory tube** and ends at the nasopharynx with the **slit-like pharyngeal opening.** The pharyngeal openings are marked by tubal tonsils in ruminants.

The **auditory tubes** serves to equalise atmospheric pressure on the two sides of the tympanic membranes. They temporarily open during yawning or swallowing. Sometimes the pressure becomes unbalanced (e.g. during a ride in an elevator) and its sudden restoration causes the ears to "pop". They also permit the slight secretion from the glands in the lining of the auditory cavity to drain into the pharynx.

The **paired guttural pouches** are a characteristic anatomical feature of equids. They are formed by the outpouching

Abb. 17-20. Auditory tube of the horse (courtesy of Dr. R. Macher, Vienna).

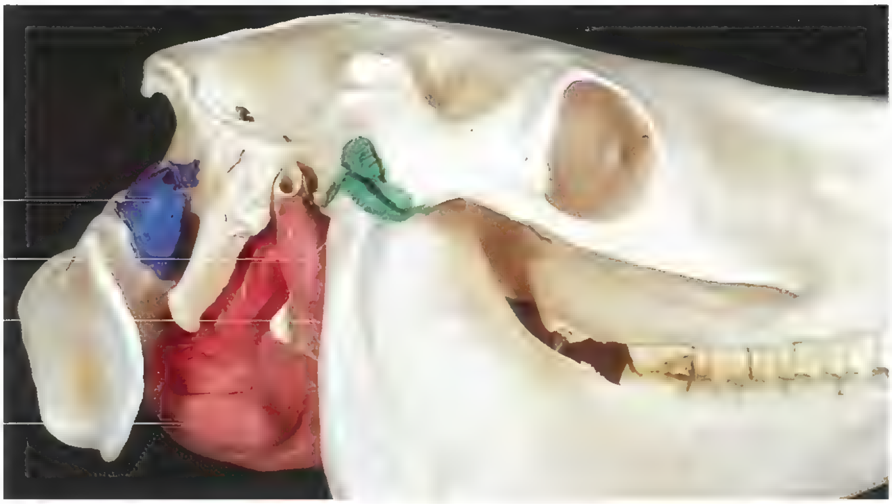


Abb. 17-21. Guttural pouch with atlantooccipital and temporomandibular articulation (acryl cast), lateral aspect (Wolf, 1999).

Fig. 17-22. Guttural pouches (acryl cast), lateral aspect.

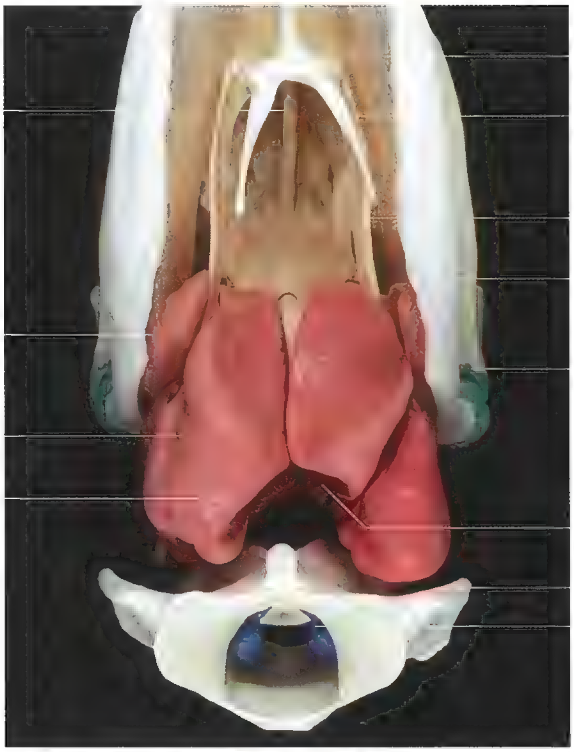


Fig. 17-23. Guttural pouches (acryl cast), ventral aspect.

of the mucosal lining of the auditory tube through the ventral slit of the supporting cartilage (Fig. 17-20 and 21). It has a capacity of about 500 ml and occupies the space between the base of the skull and the atlas dorsally and the pharynx and the beginning of the esophagus ventrally.

Medially the **dorsal parts** of the two sacs are separated by the ventral straight muscles of the head, but below this they meet, separated by a thin **median septum.** The stylohyoid bone incompletely divides the pouch into medial and lateral compartments. Several important structures are in close anatomical relationship to the pouch. These include the **external carotid artery,** which runs in a fold of the lateral wall of the lateral compartment. The **internal carotid artery** passes across the larger medial compartment, in a common fold with the **vagus** and the **glossopharyngeal nerves** and the **cranial cervical ganglion.** The glossopharyngeal and hypoglossal nerves pass along a more ventrally located fold in the wall of the medial compartment. The guttural pouches are in contact with the medial and lateral **retropharyngeal lymph nodes** and are lined by respiratory mucosa with ciliated epithelium, goblet cells and lymphoid tissue.

Guttural pouch disorders are relatively common in the horse and include guttural pouch tympany in foals, guttural pouch empyema and guttural pouch mycosis. Infection may spread onto related structures and lead to further complications.

Internal ear (auris interna)

The internal ear is a composite organ, that consists of an interconnected series of membranous fluid-filled ducts and chambers, the **membranous labyrinth** (labyrinthus membranaceus) (Fig. 17-13 and 24 to 26). The fluid within this labyrinth is called **endolymph** and its movements stimulates sensory cells within the membranous wall.

The membranous labyrinth comprises the:

- Vestibular labyrinth (labyrinthus vestibularis) containing the receptor organ for balance,
- Cochlear labyrinth (labyrinthus cochlearis) with the organ of hearing,
- Both systems communicate through the ductus reuniens (Fig. 17-13).

The **membranous labyrinth** is surrounded by the **osseous labyrinth** (labyrinthus osseus), a complex structure within the petrous temporal bone. Its shape and partitions are similar to those of the membranous labyrinth, but it is slightly larger (a more detailed description can be found in histology textbooks). The bony labyrinth consists of the:

- Vestibule (vestibulum),
- Semicircular canals (canales semicirculares ossei),
- Cochlea.

The **vestibule** is the central chamber of the osseous labyrinth. It communicates with the **cochlea** rostrally and with the **semicircular canals** caudally. The lateral wall of the vestibule has two windows: the **vestibular window,** occluded by the stapes and ventral to it the **cochlear window,** which is covered by the secondary tympanic membrane. The semicircular canals house the semicircular duct of the vestibular labyrinth.

Fig. 17-24. Osseous labyrinth of a dog, (acrylic cast) (courtesy of Prof. Dr. M. Navarro and Prof. Dr. Ana Carretero, Barcelona).

Fig. 17-25. Radiograph of the tympanic cavity and the osseous labyrinth (courtesy of Prof. Dr. Cordula Poulsen Nautrup, Munich).

Fig. 17-26. Semicircular canals.

The **cochlea** is very similar in shape to a snails shell. It forms a spiral around a central hollow core of bone, the **modiolus,** which contains the **cochlear nerve** (Fig. 17-25 and 26). The spiral consists of three turns in carnivores, 2.5 turns in the horse, four in the pig and 3.5 turns in ruminants. Projecting into the spiral canal from the modiolus is an osseous shelf, the **spiral lamina,** which incompletely bisects the lumen into two portions, called the **scala tympani** and **scala vestibuli** (Fig. 17-25 and 26). The **spiral ganglion** of the **cochlear nerve** lies within the spiral lamina. The cochlea houses three membranous ducts, which wind around the modiolus.

Between the osseous and the membranous labyrinths are **fluid-filled clefts** (spatia perilymphatica), which are connected to the **subarachnoid space** of the meninges by the vestibular

Fig. 17-27. Sectioned cochlea of a cat in dorsal recumbency (Hartmann, 1992).

and cochlear aqueducts (Fig. 17-13). The clefts are lined by a squamous epithelium and contain perilymph, which has a composition similar to cerebrospinal fluid.

Vestibular labyrinth (pars statica labyrinthi)

The vestibular labyrinth comprises the **saccule** (sacculus), the **utricule** (utriculus) and the **semicircular ducts** (ductus semicirculares). There are sensory maculae within the wall of the sacculus and utriculus and a sensory crista within each ampullae of the semicircular ducts (Fig. 17-13 and 24 to 26). They sense and conduct impulses of balance via the **vestibular nerve.**

Saccule (sacculus) and utricle (utriculus)

The saccule and utricule are two enlargements within the osseous vestibule. From the utricule arise the **three semicircular ducts** concerned with balance and from the saccule arise the **spiral cochlear duct,** which is concerned with hearing.

The **wall** of the **saccule** and **utricule** is covered by a single-layered squamous epithelium with an underlying loose connective tissue. The medial wall is thickened to form the elevated and oval-shaped **maculae** of the **saccule** and the **utricule** (macula sacculi, macula utriculi) (Fig. 17-13). The sensory maculae consists of modified epithelial cells, that act as receptors and are innervated by vestibular nerve fibres. The basal part of the epithelial cells are surrounded by a fine network of non-myelinated nerve fibres, that converge to finally form the vestibular nerve. The luminal part of these receptor cells has a gelatinous layer, which surrounds sensory hairs. Adhering to the gelatinous layer are small, calcium carbonate crystals, called otoliths. A change in the direction of the membrane exerts pressure and stimulates the receptor cells. The initiated impulse is then transmitted to the brain by efferent fibres of the vestibular nerve. The maculae thus record changes in the vertical or horizontal plane (linear acceleration).

Semicircular ducts (ductus semicirculares)

The **three semicircular ducts** are housed within the semicircular canals of the **osseous labyrinth.** Each duct arises from the utricle, and is semicircular, forming two-thirds of a circle in a single plane before it returns to the saccule. Thus each duct has **two crura,** but the anterior and posterior ducts unite to form a common crus. **One crus of each duct** has a dilatation, the **ampulla,** near the junction with the utricle.

The semicircular ducts stand roughly at right angles to each other. The anterior duct is orientated in a transverse plane, the posterior in a sagittal plane and the lateral duct in a horizontal plane.

The **structure of the wall** of the ducts is similar to those of the saccule and utricle (Fig. 17-13 and 22). Within each ampullae protrudes a ridge-shaped thickening, that marks the sensory **ampullary crest** (crista ampullaris). Sensory hairs project from the receptor cells, which are stimulated by the movement of the glycoprotein layer **(cupula)** surrounding it. Rotation induces movement of the endolymph, that deform the cupula and stimulates the receptor cells. (A more detailed description can be found in histology and physiology textbooks.)

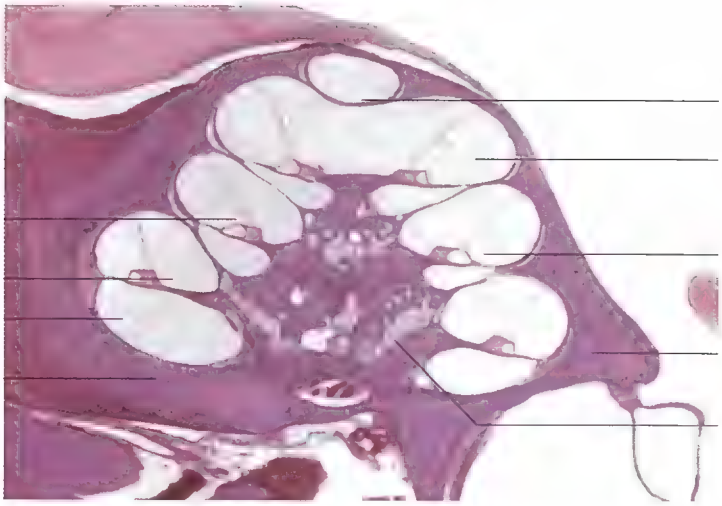


Fig. 17-28. Histological section of the cochlea of a pig in dorsal recumbency (Liebich, 2004).

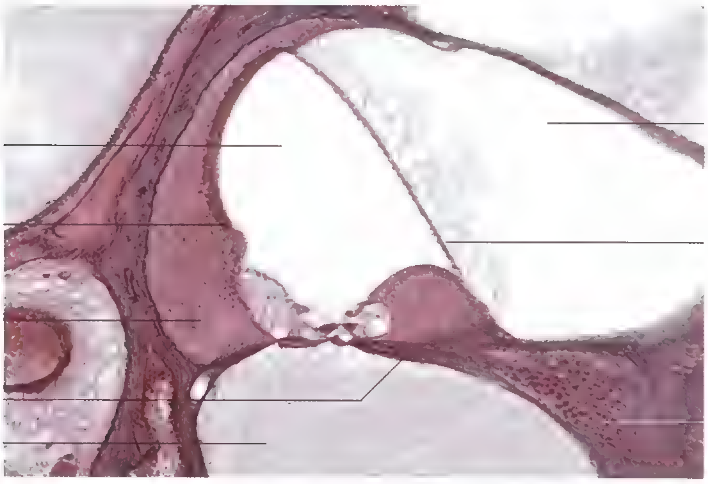


Fig. 17-29. Histological section of the scala tympani, Scala vestibuli and the cochlear duct of a pig in dorsal recumbency (Liebich, 2004).

The **receptor cells of the vestibular labyrinth** receive their sensory nerve supply from the vestibular portion of the **vestibulocochlear nerve.** The related vestibular ganglion is located within the internal acoustic meatus and extends direct branches to the vestibular receptor cells.

Cochlear labyrinth (pars auditiva labyrinthi)

The organ of hearing is located in the wall of the membranous cochlear labyrinth and consists of the **organ of Corti** (organum spirale) within the **cochlear duct** (ductus cochlearis) (Fig. 17-13 and 24, 25 and 27).

The spiral canal of the cochlea is divided into **three membranous ducts,** which spiral around the modiolus to the apex of the cochlea (Fig. 17-13 and 25 to 27):

- Scala vestibuli,
- Cochlear duct, also called the scala media,
- Scala tympani.

The upper channel is the **scala vestibuli,** the middle the **cochlear duct** and the lower the **scala tympani.** The two scalae communicate at the apex of the cochlea **(helicotrema)** around the blind end of the cochlear duct. At the base of the cochlea the scala vestibuli begins at the **vestibular window** and the scala tympani at the secondary tympanic membrane, which covers the **cochlear window.** Both scalae are lined with a single layered epithelium and filled with perilymph.

The cochlear duct begins blindly and passes up inside the spiral canal of the osseous cochlea and ends blindly at the apex of the modiolus. It is filled with endolymph and is in communication with the vestibular labyrinth via the ductus reuniens.

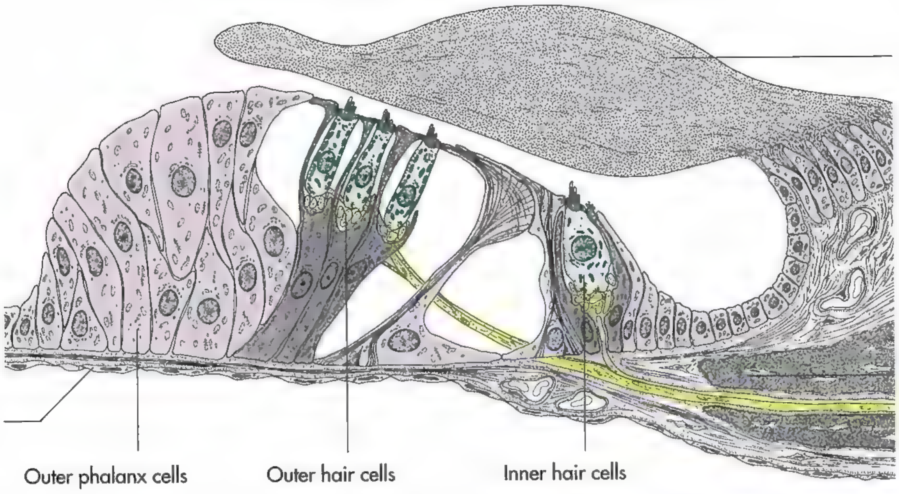


Fig. 17-30. Schematic illustration of the organ of Corti in an animal in dorsal recumbency (Liebich, 2004).

Cochlear duct (ductus cochlearis)

The cochlear duct winds around the modiolus between the two scalae. It appears wedge-shaped in cross section with the apex pointing towards the modiolus. Within it lies the organ of Corti immersed in endolymphatic fluid (Fig. 17-28). The walls of the cochlear duct have **three distinct segments: tympanic membrane, vestibular membrane** and **lateral membrane** (Fig. 17-26 and 27). The very thin vestibular membrane forms the roof of the cochlear duct, separating it from the scala vestibuli of the cochlea. The **lateral wall of the cochlear duct** is formed by the **spiral ligament** (ligamentum spirale), which is firmly adherent to the underlying periosteum of the spiral lamina. It is richly vascularised and responsible for the production and the **secretion of endolymph.**

The **tympanic membrane** forms the floor of the cochlear duct and separates it from the scala tympani. The organ of Corti is part of the tympanic membrane. Its connective tissue component is the **basilar lamina,** which is derived from the periosteum of the spiral lamina and is continuous with the spiral ligament of the lateral wall of the cochlear duct.

Organ of Corti (organum spirale)

The organ of Corti or spiral organ includes the **receptor cells for hearing.** It lies on the tympanic membrane of the cochlear duct and follows the spirals throughout the cochlea (Fig. 17-28). Towards the interior of the duct it is covered by a gel-like membrane **(membrana tectoria).**

The organ of Corti includes two different types of cells:

- Sensory cells,
- Supporting cells: Columnar and phalangeal cells.

The **columnar cells** contact the basilar membrane with one end, while the other end is extended to form plates, which provide stability to the receptor cells of the organ of Corti. The columnar cells are assisted by the **phalangeal cells,** which also support the receptor cells. The receptor cells are arranged in rows between the phalangeal cells. They are cylindrical cells, whose base synapse with one or more afferent and efferent neurons. Sensory hairs project from the free end of the receptor cells (Fig. 17-28).

Sounds are received by the external ear and provoke mechanical vibrations of the tympanic membrane, which are transmitted to the inner ear by the chain of auditory ossicles. Since the stapes is in direct contact with the vestibular window, the perilymph of the inner ear is set in motion. Due to the incompressible nature of fluids, the movement of the perilymph is transmitted via the scala vestibuli, the helicotrema and the scala tympani to the cochlear window, where it induces vibration of the secondary tympanic membrane. Different frequencies are transmitted to the endolymph of the cochlear duct by the vestibular membrane. Movement of the endolymph results in pressure on the tectorial membrane, which in turn induces pressure on the sensory hairs, that stimulate the receptor cells to send impulses to the spiral ganglion. The axons of the spiral ganglion unite to form the cochlear part of the vestibulocochlear nerve, which passes to the corresponding nuclei of the medulla oblongata.

Clinical terms related to the ear:
Otitis, otoscopy, auriculotemporal syndrome, tympanometry, tympanoscopy.

18 Common integument (integumentum commune)

H. Bragulla, K.-D. Budras, Chr. Mülling, S. Reese and H. E. König

The common integument, often inaccurately referred to as the skin, forms the outer barrier of the organism and the interface to the environment. It is the largest organ of all the mammals and fulfils a multitude of functions:

- Protection of the body against mechanical, chemical, physical and biological factors within the environment,
- Receptors for the perception of pressure, pain, heat and cold,
- Storage and excretion of water, electrolytes, vitamins and fat,
- Thermoregulation,
- Immunological defence and
- Communication.

The role of the common integument is vital, such that loss of 25% results in usually fatal complications. Furthermore, the common integument may reflect the state of health of the animal and indicate internal disease, manifesting as icterus, cyanosis or oedema. The common integument has also a considerable economic value with regards to the leather, fur and wool industry.

During evolutionary development, the common integument has developed several specialised structures in adaptation to its complex function:

- Subcutaneous tissue (subcutis, tela subcutanea),
- Skin (cutis) with dermis, epidermis and hairs,
- Modifications:
  - Skin glands (glandulae cutis), including the mammary glands,
  - Foot pads (tori),
  - Enclosure of the distal phalanx: nail, claw, and hoof,
  - Horn (cornu).

Fig. 18-1. Pedigree bull with characteristic median skin fold at the caudal end of the neck (dewlap).

Fig. 18-2. Head of a billy-goat with species-characteristic modifications of the common integument: tassels, long beard hairs and horns.

Subcutaneous layer (subcutis, tela subcutanea)

S. Reese

The subcutis is the loose connective tissue layer between the skin and the superficial fascia. The **superficial fascia** is regarded to be part of the external fascia of the trunk, but also constitutes the **fibrous layer** (stratum fibrosum) of the subcutis. The **subcutis** consists of loose connective tissue interspersed with white fat. The fat serves as protection against cold, energy reservoir and as padding (e.g. footpads).

More substantial **accumulations of fat** (panniculus adiposus) are found in the subcutis of the pig, and in the nuchal region of the horse. The composition of the subcutaneous fat is typical for each species: it is yellowish and oily in the horse, white and dry in the ox and greyish-white and firm in the pig. Brown fat is only temporarily present in the domestic mammals during the perinatal phase. It is found in the nuchal and shoulder region and serves for thermogenesis in the newborn.

Distinct soft tissue bundles pass through the subcutis attaching it to the underlying tissue. **Cutaneous muscles** between the two layers of the superficial fascia extend minute tendons into the subcutis and provide the means for active movement of the skin. The **subcutis** of the sheep, dog and cat includes large amounts of loose connective tissue, while the subcutis of the horse, ox and goat is more tightly adherent to the trunk. Local thickening of the subcutis enables the skin to form **folds** (plicae cutis) (Fig. 18-1). Examples where animals have excessive subcutis include the brisket of the ox, the neck of the sheep, the popliteal region and intermandibular region between the cervical appendages. Several goat breeds and some pigs and sheep have paired cylindrical appendices hanging from the ventral aspect of the neck, that consist of loose connective tissue around a central rod of cartilage.

Where movement of the skin is undesirable the subcutis is either very thin or even absent, e.g. over the lips, cheeks, eyelids, auricles and around the anus. A synovial bursa may be present against bony protuberances to prevent damage to soft tissues or skin (bursa synovialis subcutanea).

Skin (cutis)

S. Reese

The skin encloses the body and blends with the mucous membranes at the various openings of the digestive, respiratory, urinary and genital systems.

The **surface of the skin** is marked by a network of fine **grooves** (sulci cutis) and **ridges** (cristae cutis). These contours are most distinct in areas, where no hairs are present, such as the nose or the muzzle (Fig. 18-3). They are permanent and individually distinct and provide a means of identification, widely used in man (fingerprints), less commonly in dogs and cattle (nose printing). Additionally small, knob-like projections are found in all species, which serve as tactile receptors. Specialised **skin pouches** (sinus cutanei) are present in the

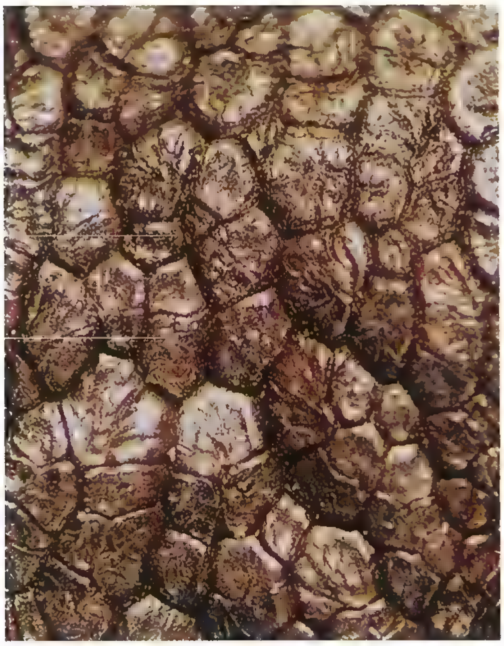


Fig. 18-3. Surface contour of the planum nasale of a dog.

Fig. 18-4. Interdigital pouch of a sheep, sagittal section.

sheep, cat and dog, in which the secretion of skin glands and sloughed surface cells combine to form a strong smelling mixture, used for marking. In sheep these are the infraorbital pouch (sinus infraorbitalis), the inguinal pouch (sinus iguinalis) and the interdigital pouches (sinus interdigitalis), which are present in all four limbs. In the dog and the cat, the circumanal pouches release their secretions during defecation or voluntarily by contraction of the external sphincter of the anus.

The skin can be further subdivided into the:

- Dermis (corium), the deep connective tissue layer,
- Epidermis, the superficial epithelium.

Dermis (corium)

The dermis or corium represents the **soft tissue structure** of the integument. It is this part of the skin that forms leather following the tanning process. It contributes the majority of the thickness of the integument. The thickness of the dermis varies in different species and body areas. Generally the thickest dermis is found in cattle and the thinnest in sheep and cats. From the dorsal to the ventral aspect of the abdomen the thickness of the dermis decreases. In the legs from proximal to distal. The dermis is more developed on the extensor side of joints than on the flexor side. Older, uncastrated boars possess an especially tough and thick dermis in the neck, shoulder and lateral thoracic area.

The dermis is largely composed of **collagen fibre bundles,** that are arranged parallel to the surface of the skin. The interlacing fibres form a dense network that accounts for the increased tensile strength of the integument. **Elastic fibres** forming an additional network, make the integument pliable. These fibres interlace with the soft tissue of the hair shafts and provide a stable yet elastic suspension of the hair follicle within the thin epidermis.

The orientation of the collagen and elastic fibres differs with the body region, creating so-called **split lines.** These split lines can be demonstrated by creating a circular incision, which will result in a slit along the direction of these fibres. It is essential for the surgeon to know the general orientation of theses fibres in order to make incisions parallel to them, thus reducing tension within the incision. Incisions and wounds perpendicular to the fibres result in wide, gapping wounds.

The dermis can be further subdivided into:

- Reticular layer (stratum reticulare),
- Papillary layer (stratum papillare).

The **dense reticular layer** is rich in fibres, poor in cells and lies directly on the subcutis. The **papillary layer** underlies the epidermis and is rich in blood vessels and cells. Contact between the papillary layer and the epidermis is increased by the development of ridges and papillae. These structures are summarised as the papillary body, which has two main functions: it increases the mechanical adhesion between the dermis and the epidermis and enhances diffusion of nutritional substances from the well-vascularised dermis to the non-vascularised epidermis. The papillary body is considerably developed in hairless areas, where the integument is exposed to hard wear (e.g. lips and footpads). The lack or greater demand of nutritional substances by the epidermis leads to an increased differentiation of the papillary body.

Epidermis

The epidermis is formed by a **cornified, stratified squamous epithelium** (Fig. 18-5 to 8). It is continuous with the mucous

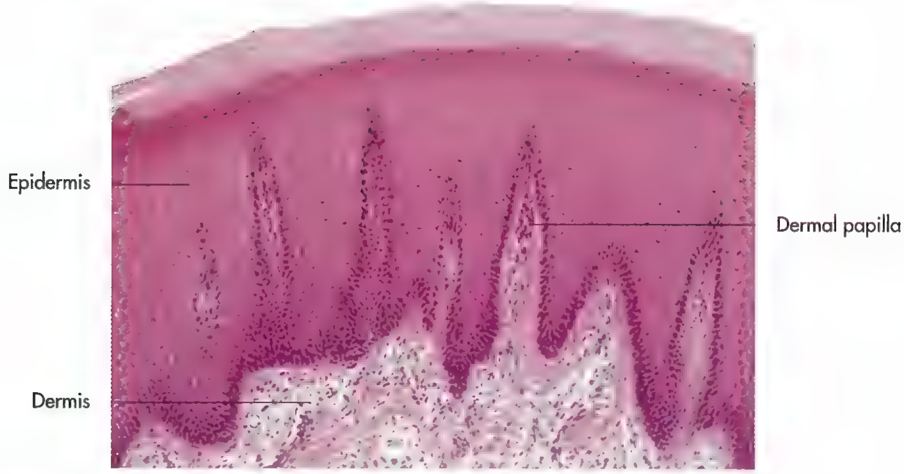


Fig. 18-5. Histological section of the foot pad of a cat with distinct papillary body.

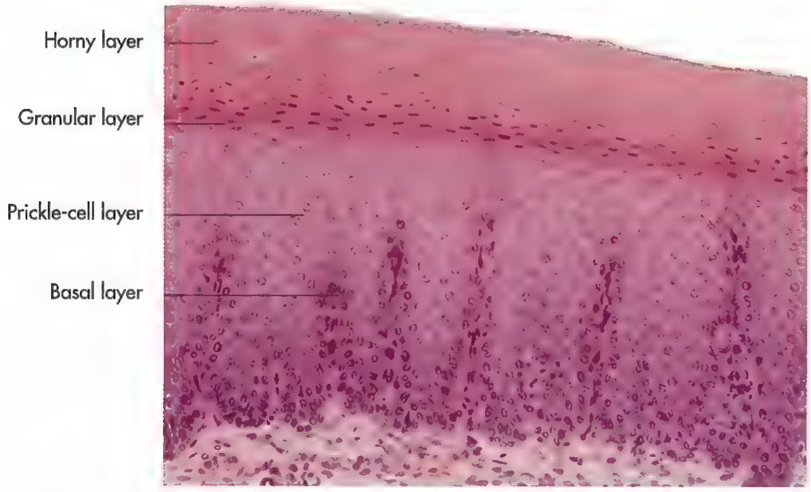


Fig. 18-6. Histological section of the epidermal layers of the lip of a horse.

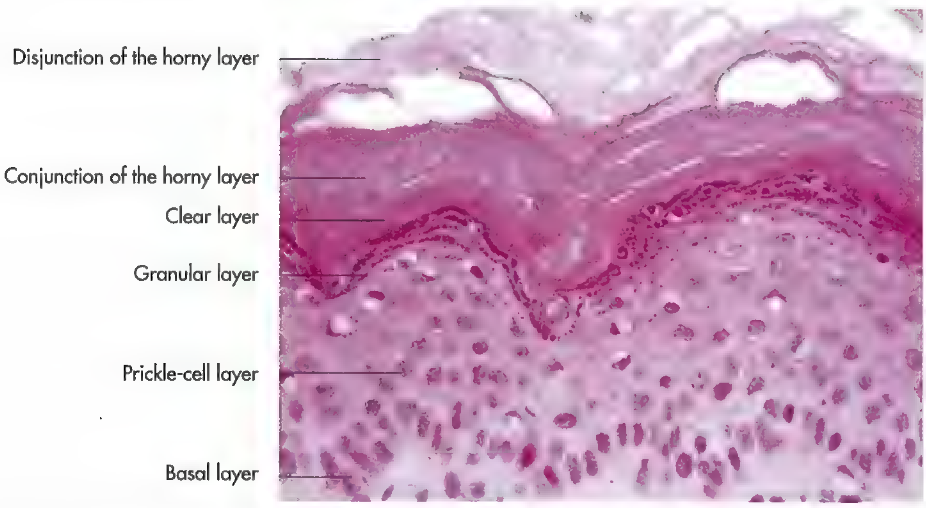


Fig. 18-7. Histological section of the epidermal layer of the foot pad of a dog with a distinct granular layer and keratinised layers.

membranes at the mucocutaneous junctions and can be differentiated from mucosa by the presence of hairs, sebaceous and sweat glands. The thickness of the epidermis varies considerably between body regions. While it is thin in the hairy skin (10-100 μm), it is ten to twenty times thicker in the non-hairy skin (e.g. planum nasale). The thickest epidermis is found in the digital pads and the hoof, where cornification of the epidermis results in horn formation.

The epidermis can be divided into five layers:

- Basal layer (stratum basale),
- Prickle-cell layer (stratum spinosum),
- Granular layer (stratum granulosum),
- Clear layer (stratum lucidum) and
- Horny layer (stratum corneum).

The most superficial layer, the **horny layer,** from which cells are sloughed continuously, is sometimes referred to as a **disjunction layer** (stratum disjunctum). The **clear layer** is in fact a remnant of young horn cells. In the domestic mammals it is present in the epidermis of the digital pads and the planum nasale of the dog and cat.

The main component (85%) of the epidermis is the **keratinocytes.** The deepest layer is the basal layer, which rests on a basement membrane underlined by the dermis. In this layer, the keratinocytes undergo mitotic cell division, followed by migration towards the surface. On their way from the basal layer to the surface the keratinocytes undergo a sequence of differentiation processes **(keratinization** and **cornification),** the end product of which is the dead cornified cell. The continuous process of proliferation, migration, keratinization, cornification and the final sloughing of the cells are regulated by feedback mechanisms, a more detailed description of which can be found in histology texts. Disturbance of the regulatory mechanisms, as often seen with skin diseases, typically results in hyperkeratosis.

A complete cycle from the fresh cell to its desquamation usually takes between 20 and 30 days, depending on the species. The quality of keratinization and cornification is largely dependent on nutrition the cells receive. The surface available for diffusion between the dermis and epidermis is larger on the sides of the papillae **(peripapillary),** than on the tip **(suprapapillary)** or between the papillae **(interpapillary).**

Thus peripapillary horn differs from suprapapillary and interpapillary horn in structure and has better mechanical properties. In skin modifications with especially well-developed papillary body this leads to the formation of specific horn types, such as the horn tubules in the hoof.

In general two different types of cornification can be distinguished: the so-called **soft** and **hard cornification.** The soft cornification takes place in association with the granular layer and is the typical process for the skin. The hard type is a modification of the cornification process and is characteristic for the epidermis of the distal phalanx, such as the hoof and claw, where no granular layer is present.

Completely cornified keratinocytes, the horn cells, are held together by membrane coating material (MCM), thus the structure of horn can be compared with a brick wall: the cells being the brick, the MCM the mortar. MCM includes lipids, such as ceramide, which accounts for the semi-permeable properties of the stratum corneum with regards to water and water-soluble molecules, while fat-soluble molecules easily penetrate the epidermis. The water-resistant characteristic of the horny layer is essential for terrestrial mammals and birds and was a preliminary requisite for the movement of animals from aquatic to terrestrial life.

Several cell types account for the remaining 15% of the epidermis. Although small in number, these cells have an important part in the multitude of functions the integument has to fulfil. These cells are:

- Melanocytes,
- Langerhans' cells,
- Merkel's cells.

Melanocytes are responsible for the pigmentation of the skin. They produce yellowish to black pigment granules (melanosomes), that are taken over by neighbouring keratinocytes. These melanosomes group around the nuclei of the keratinocytes, thus protecting them from the mutagenic effect of UV radiation. The melanosomes account for the colour of skin providing camouflage and the colouring of specific skin regions, that expresses signals to fellow animals as well as enemies.

Langerhans' cells are part of the cellular component of the immune system and belong to the mononuclear phagocytosis system (MPS). They play an important role in the body's defence against viral infections, skin tumours and contact allergies.

Merkel's cells are especially numerous around the tactile elevations (toruli tactiles) and function as receptors to touch. They are epithelial neuroendocrine cells that respond to mechanical stimulation and convey the received information to free nerve endings within the epithelium.

Blood supply of the skin

Blood vessels to the skin and subcutis arise from a **(sub)fascial arterial network.** Arcuate arteries extend into the dermis, where they form a cutaneous network (rete arteriosum dermidis) close to the subcutis. A second, denser network (rete arteriosum subpapillare) is located between the papillary and the reticular layer of the dermis and extends capillary loops into the papillae (Fig. 18-9).

Venous drainage is achieved by three distinct plexus, all lying parallel to the surface (plexus venosus subpapillaris superficialis et profundus, plexus venosus dermidis profundus) (Fig. 18-8). These plexus are extensive and are responsible for the ability of the skin to store blood. The blood can bypass the capillary beds of the skin by means of autonomic regulatory mechanisms.

Blood flow to the skin is responsible for the loss of heat and is thus an important factor in the thermoregulation of the body. Changes in skin colour brought about by blood flow to the skin is part of the social interaction and communication system (e.g. blushing in people or changing of the colour of the wattle and comb in poultry).

Lymphatic drainage starts in the epidermis with minute sinusoids (sinus lymphatici initiales), which drain into modi-

Fig. 18-8. Skin with sinus hair, schematic (Liebich, 2004).

fied lymph capillaries. These lymph capillaries form a **deep capillary network** (rete lymphocapillare cutis profundum). The vessels arising from this network drain into a **subcutaneous lymphatic plexus** (rete lymphocapillare subcutaneum) (Fig. 18-8). From this plexus drainage is achieved via local lymph nodes, which are located mostly superficially and are thus palpable in most cases (e.g. axillary lymph node, superficial inguinal lymph node, popliteal lymph node).

Nerves and sense organs of the skin

The dermis, as well as the subcutis, receives an ample **autonomic** and **sensory innervation.** The autonomic nerve fibres form perivascular plexus in order to provide sympathetic innervation of the blood vessels, skin glands and the smooth musculature of the skin (mm. arrectores pilorum). There is no parasympathetic supply to the skin.

Sensory nerve fibres form plexus within the subcutis and dermis (plexus nervorum subcutaneous, dermidis et subepidermidis). They terminate either in free endings or in end bulbs (Fig. 18-8). A part of the **free nerve endings** extend into the epidermis after loss of their glial sheaths. Based on their function one can distinguish three different types of nerve endings: type one is sensitive to mechanical pressure, the second type is sensitive to temperature and the third acts as a pain receptor.

Interspersed within the integument are hair follicle receptors, which are sensitive to pressure and touch. Apart from the free nerve endings, there are Merkel cells within the dermis, Meissner's corpuscles in the papillary layer and Pacinian corpuscles within the subcutis (Fig. 18-8 and 10).

The following structures act as **thermal receptors:** End bulbs of Krause are found in the papillary layer and respond to cold, Ruffini corpuscles are found in the reticular layer and are responsive to warmth (Fig. 18-8).

Pain is registered by convoluted free nerve endings, without glial sheaths. A more detailed description can be found in histology textbooks.

Small nerve branches are generally distributed in a segmental pattern in all areas of the body. On the head they originate from the cutaneous components of cranial nerves. Along the body, the cutaneous nerves are branches of the spinal nerves.

The various segments of the spinal cord are responsible for innervation of certain inner organs as well as the skin. Disease of a certain organ can cause changes in the corresponding skin region **(head zone).** This phenomenon is described as a vis-

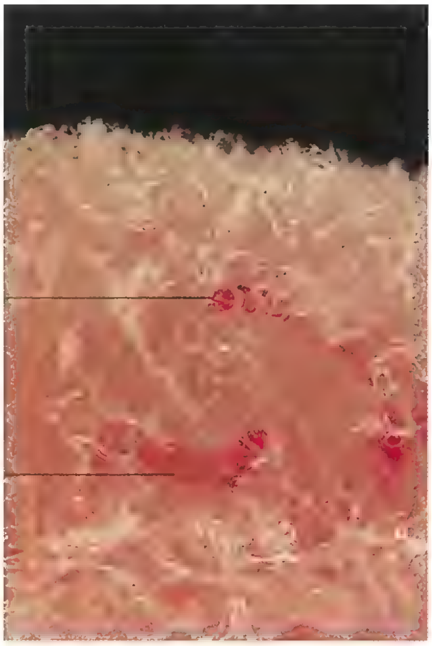


Fig. 18-9. Blood vessels of the dermis, corrosion cast.

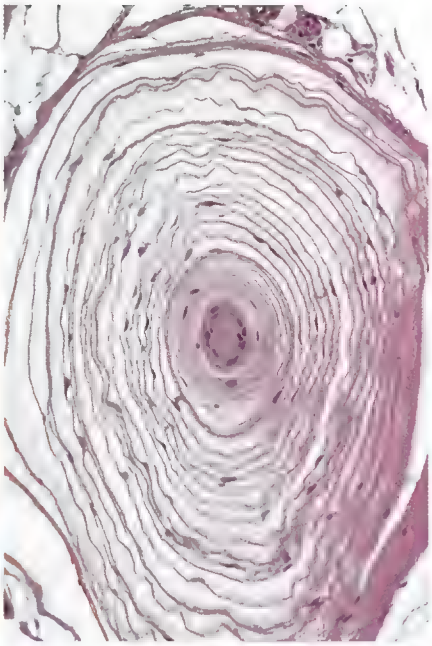


Fig. 18-10. Pacinian corpuscle.

cerocutaneous reflex. A classic example of this is the hypersensitivity of the region of the withers in cows, suffering from traumatic reticulitis, caused by a foreign body.

Hairs (pili)

S. Reese

Hair is a feature of the skin, that is class specific for mammals. In most species, the haircoat is spread over the whole body with the exception of a few body regions, such as the nose, digital pads, teats, claws and hooves. Even in so-called 'naked' or hairless dogs, there are still hairs present, although they are reduced in size and number.

Hairs are essentially long, thin, elastic columns of horn, formed by the epidermis (Fig. 18-14 and 15). Each hair consists of a **central medulla** or **core** (medulla pili), a **cortex** (cortex pili) and an **outer cuticle** (cuticula pili). However, not all hair types have the same architecture, e.g. in wool hair, the medulla is absent. Longitudinally each hair can be divided into the:

- Hair shaft (scapus pili), that protrudes above the surface of the skin,
- Hair root (radix pili), that takes an oblique course to anchor the hair in the dermis, but is only fully developed during hair growth,
- Bulb of hair (bulbus pili), a proximal enlargement of the root within the epidermis, that encloses the dermal papilla (papilla pili).

The root of the hair is embedded within the **hair follicle** (folliculus pili), that constitutes the basic unit of hair production. The follicle wall is divided into two layers, the **outer mesodermal** (vagina dermalis radicularis) and **inner ectodermal** (vagina epithelialis radicularis) root sheaths (Fig. 18-15). Sebaceous and sweat glands open into the hair follicles (see section about skin glands).

The hair can be involuntarily moved by **smooth muscles,** the **arector muscles of the hair.** A tiny arector muscle of the hair passing from an attachment near the dermal papilla joins the proximal end of each follicle. Contraction of these muscles result in erection of hair from its normally oblique position. It improves thermal isolation of the body during low temperatures and gives an animal a threatening appearance. Though functionally unimportant in humans, its still obvious as 'goose pimples'.

The **colour of the hair** is determined by the type and number of melanin granules within the keratinocytes and the amount of air trapped within the medulla of the hair. (A more detail description can be found in histology textbooks.)

Hair types

There is a great deal of variability in hair length, colour, diameter, transverse contour among the various species and breeds. Straight, rather stiff **guard hairs** (capilli) provide the topcoat in all domestic mammals other than the sheep. Fine, wavy **wool hairs** (pili lanei) provide the undercoat. These hairs are most numerous during the winter. In sheep the fleece is exclusively of this hair type. Stout tactile hairs with a restricted distribution are associated with touch receptors.

There are **three basic hair-coat types** based on hair length: normal coat, which is typified by the German Shepherd, the short-hair coat, typified by the Boxer and the long-hair coat, typified by the Chow. There are many variations among the different types, such as the wire-hair coat. The stiff, sparsely scattered bristles of pigs constitute a species spe-

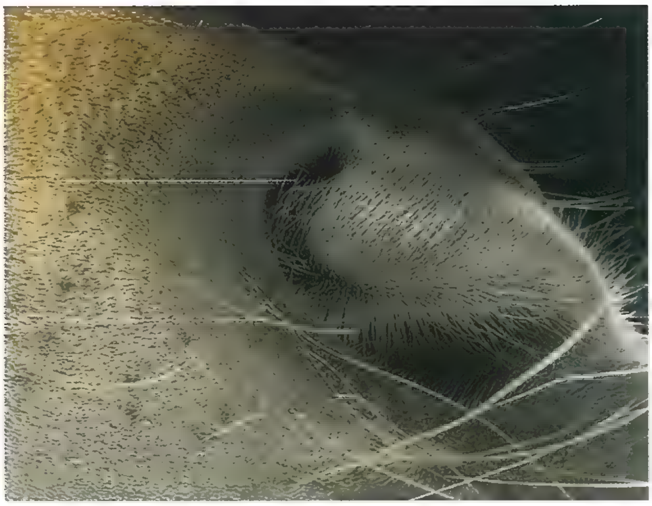


Fig. 18-11. Guard hairs at the vestibule of the nares of a horse (vibrissae).

Fig. 18-12. The hairs of tragus around the ear (tragi).

Fig. 18-13. Eyelashes (cilia) of the upper lid of the horse.

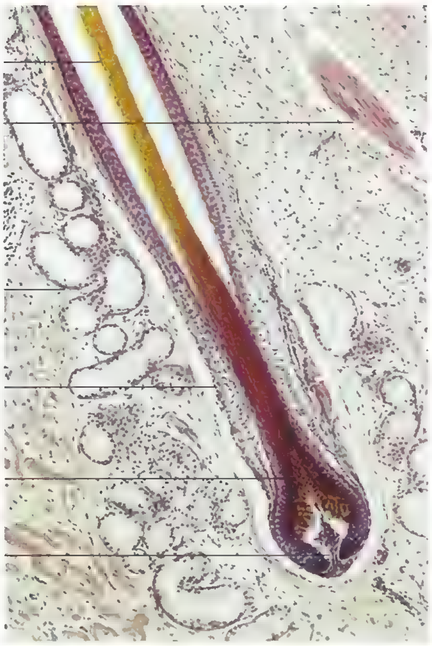


Fig. 18-14. Histological section of a hair follicle (Liebich, 2004).

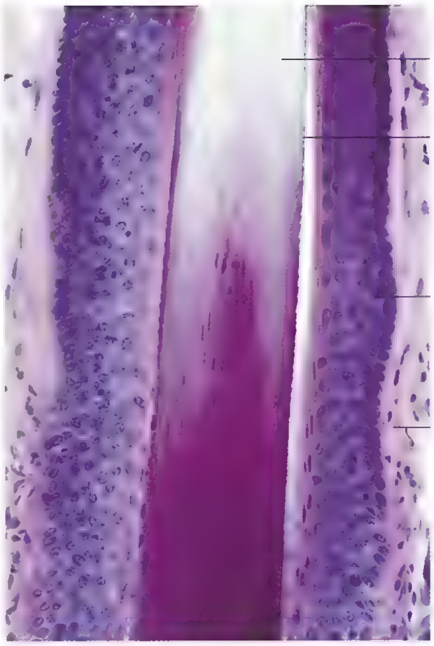


Fig. 18-15. Histological section of hair with hair shaft (Liebich, 2004).

cific modification of guard hairs. Local variations in the form and development of guard hairs include the coarse hair of the **mane** (juba), **tail** (cirrus caudae) and the **fetlock tufts** (cirrus metacarpeus/metatarseus) of horses, the long tail hairs of cattle and pigs and the **beard hairs** (barba) of some goat breeds (Fig. 18-2). Special modifications of guard hairs are the hairs of the **vestibule of the nose** (vibrissae), the **hairs of tragus** around the ear (tragi) and the **eyelashes** (cilia).

Tactile hairs are a modification of the guard hairs (Fig. 18-8, 16 and 17). They are found on the head with the exception of the tactile hair at the carpus of the cat (pili tactiles carpales). They are substantially thicker and generally protrude beyond the neighbouring guard hairs. Their roots reach deeply into the subcutis and each is surrounded by a venous sinus within whose walls there are nerve endings responsive to touch.

The following survey presents tactile hairs, their names indicating their location:

- Supraorbital tactile hairs,
- Infraorbital tactile hairs,
- Zygomatic tactile hairs,
- Buccal tactile hairs,
- Mental tactile hairs,
- Tactile hairs of the upper lip (whiskers of the cat) and lower lip.

Patterns of hair

Guard hairs mostly lie close to the skin and sweep uniformly in broad tracts giving the coat a smooth appearance. The general direction taken by these bundles is referred to as **hair streams** (flumina pilorum). The regular pattern of the hair stream is interrupted, where different bundles converge, diverge or combine and **whorls** (vortices), **crests** (linea pilorum convergens), **crosses** (cruces) and **partings** (linea pilorum divergens) are formed (Fig. 18-18 and 19).

Generally the length and the diameter of the single hair decreases from dorsum to ventrum, while the density increases. However, in some breeds mutant arrangements are seen as attribute of the particular breed, particularly in dogs, cats and rabbits.

In dogs and cats, several hairs share a single follicle opening. The central (primary) hair is longest and of the guard type, while the surrounding secondary hairs are shorter and softer and of the wool type. The hair shafts that share a common opening in the skin are enclosed in a common follicle down to the level of the sebaceous glands. Below this point the hair shafts have their own individual hair follicle and bulb.

Shedding

Guard and wool hairs have a limited life-span and the coat undergoes gradual shedding with seasonal peak times in spring and autumn, where many hairs are shed together. However, the coat of one season merges into that of the next, so the animal is normally never without a protective covering. The shedding process is regulated by the pineal gland and is mainly conditioned by day length and temperature.

The **hair follicle cycle** can be divided into **three stages:** the **anagen, catagen** and **telogen** stages. The anagen stage constitutes the active growth phase and is characterised by a well-developed dermal papilla that is completely capped by the epidermal hair matrix, forming the bulb of the hair. In the next, catagen stage, growth slows and the hair matrix and the covering papilla both atrophy. The dermal bulb and the entire

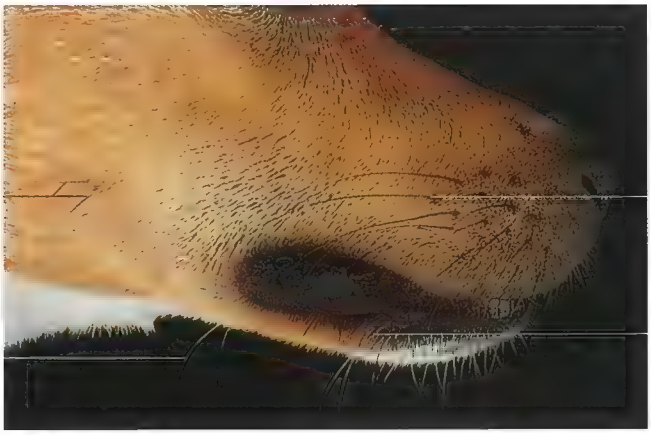


Fig. 18-16. Tactile hairs on the head of a dog.

follicle become smaller. Hair follicles in the telogen stage have a small dermal papilla, which are separated from the bulb and are no longer covered by matrix cells. The hair follicle is very short, which causes a larger part of the hair to project above the skin. When growth resumes, the reactivated follicle lengthens and extends away from the surface, thus releasing the old hair, which falls out. A replacement hair then forms in the anagen phase that follows. The new hair gradually grows from the depth of the follicle until it emerges on the surface of the skin.

Skin glands (glandulae cutis)

S. Reese

Two basic types of skin glands can be distinguished (Fig. 18-8), although each type has various sub-varieties and specialised forms:

- Sebaceous glands (gll. sebaceae),
- Sweat glands (gll. sudoriferae).

Sebaceous glands are distributed over the integument in association with hair follicles into which they drain. These glands produce a **fatty secretion** (sebum) that mixes with the secretion of the apocrine sweat glands, which also open into the hair follicle. The combined secretion is distributed over the whole body surface and lubricates and waterproofs the skin and coat. The **tarsal glands of the eyelids** (Meibomian glands), the sebaceous glands of the lips and around the anus are specialised sebaceous glands, which are not associated with hairs. In the pig sebaceous glands are sparse and rudimentary.

Sweat glands can be further subdivided based on the histology of their secretory process into (Fig. 18-8 and 14):

- Eccrine sweat glands,
- Apocrine sweat glands.

Apocrine sweat glands are more common and discharge their albuminous sweat into hair follicles over most of the body. Their secretion provides the **individual odour,** characteristic of each animal (glandula odorifera). These glands are especially numerous in the horse, where they have additional openings on the skin surface around hair follicles. Since the apocrine sweat is rich in protein, the horses' sweat froths when worked by movement of the skin and coat ("lathering up").

Eccrine sweat glands are not associated with hairs and secrete a more watery sweat directly onto the skin. This type predominates in primates, in which it accounts for the typical sour protection film on the skin (pH of the skin of primates is around 5, compared to a pH of 7 in domestic mammals). In the domestic mammals, they are only found in certain hairless or nearly hairless regions of the skin, e.g. the footpads of dogs.

Specialised forms of skin glands

Skin glands form localised accumulations, the size, form and location of which varies among species. Some of them show specialised modifications and several are associated with skin pouches. In some domestic mammals, the secretion of these glands functions as sexual or territorial markers. The following glands are found in the domestic species, their names indicating their location:

- Perianal glands (gll. sinus paranalis): Sebaceous and serous glands in the wall of the anal sac in dogs and cats,
- Circumanal glands (gll. circumanales): Sebaceous glands in the vicinity of the anus of the dog,
- Tail glands (gll. caudae): Sebaceous and serous glands on the dorsum of the tail in the cat and rudimentary in the dog,
- Circumoral glands (gll. circumorales): Sebaceous glands in the lips of the cat,
- Skin glands of the footpads in carnivores and the frog of the horse (gll. tori),
- Mental glands (gll. mentales) and carpal glands (gll. carpeae): apocrine sweat glands in the pig,
- Glands of the infraorbital pouch (gll. sinus infraorbitalis),
- Glands of the interdigital pouch (gll. sinus interdigitalis),

Fig. 18-17. Tactile hairs (pili tactiles carpales) at the carpus of a cat.

Fig. 18-18. Hair whorl (vortex pilorum divergens) in a dog.

Fig. 18-19. Hair crest (linea pilorum convergens) in a horse.

- Glands of the inguinal pouch (gll. sinus inguinalis) in the sheep,
- Horn glands (gll. cornuales) in the goat,
- Glands of the ear canal (gll. ceruminosae): Apocrine and sebaceous glands, that produce cerumen, present in all domestic mammals.

The nose is kept moist by planum rostrale glands, nasolabial or nasal glands, depending on the species. These glands are not present in the cat and dog. The largest and most important modified skin gland in domestic mammals is the mammary gland. This organ is described separately and in detail in the next chapter.

Mammary gland (mamma, uber, mastos)

H. Bragulla and H. E. König

The presence of mammary glands (glandula mammaria) and the process of lactation are unique to mammals (mammalia). Based on their microanatomy, mammary glands are modified sweat glands of the exocrine, tubuloalveolar type.

The **mammary gland** consists of a species specific number of **mammary complexes,** that are arranged in a bilaterally symmetrical order to either sides of the midline on the ventral aspect of the trunk. In carnivores and in the pig the mammary glands extend from the thoracic to the inguinal region, while in ruminants and the horse they are restricted to the groin and are collectively referred to as udder (uber) (Fig. 18-20 and 21). Each mammary complex consists of one or several mammary units, that comprises a **body** (corpus mammae) and a **teat** (papilla mammae) (Fig. 18-22). The relative size and the length of the mammary gland vary among individuals and with the functional stage the gland is in (juvenile, lactation, postlactation). The skin covering the teats is hairless, while the skin over the mammary body has some hairs, depending on the species. Usually the skin can be easily moved against the underlying glandular tissue and only in the case of a disease process does the skin becomes tightly adherent to the underlying tissue. Other diagnostic signs of mastitis are pain, raised temperature and swelling of the affected gland.

Milk is the characteristic secretion of the mammary glands and serves for nourishment of the young. The first milk after parturition, the colostrum, has a high antibody content, which provides the newborn with passive immunity. Because of its composition, the milk of ruminants, especially of cows is an important component of human food. (For more information see textbooks of physiology.)

Diseases affecting the mammary glands are of clinical importance: Inflammation of the mammary glands **(mastitis)** is a common condition in the dairy cow and causes considerable economic losses. Neoplasms of the mammary glands of the bitch are not uncommon, especially in older animals and often need surgical removal. This requires a detailed knowledge of the anatomy of the mammary glands with special regards to suspension, blood supply, lymphatic drainage and innervation.

Suspensory apparatus of the mammary glands

The mammary glands are suspended from the ventral aspect of the trunk by the superficial and deep layer of the external fascia of the trunk, which form the so-called **suspensory apparatus** (apparatus suspensorius mammarius). It

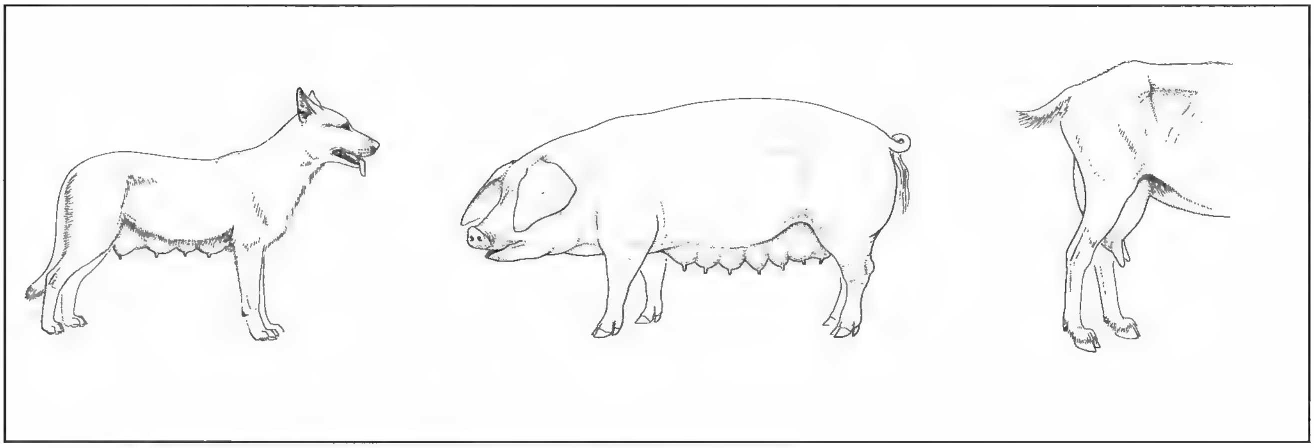


Fig. 18-20. Mamma of the bitch and sow, udder of a she-goat, schematic.

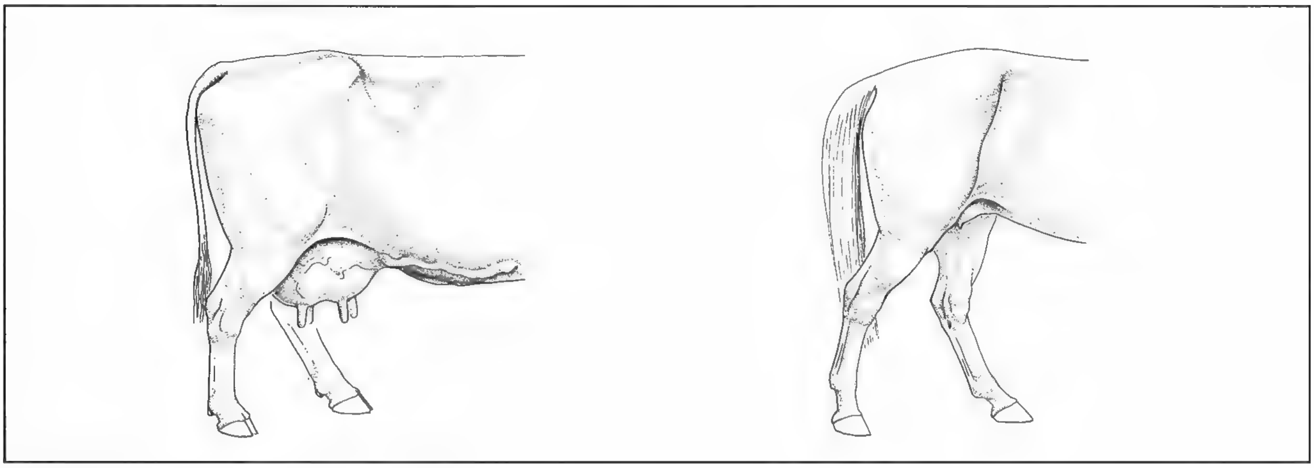


Fig. 18-21. Udder of a cow and mare, schematic.

consists of **lateral** (laminae laterales) and **medial fascial sheets** (laminae mediales) from which thin **lamellae** (lamellae suspensoriae) extend between the mammilary complexes (Fig. 18-22). The medial lamina is largely composed of **elastic tissue,** the lateral lamina is of **dense connective tissue.** The left and the right rows of mammary complexes are divided by the **intermammary groove** (sulcus intermammarius).

Structure of the mammary glands

Each mammary complex comprises one ore more mammary units. The **mammary body** (corpus mammae) consists of epithelial **glandular tissue** (glandula mammaria) and interstitial **connective tissue** (interstitium) with nerves, blood and lymph vessels (Fig. 18-22, 25 and 26). The mammary unit ends with a system of ducts, which show a species-specific arrangement and end at the **tip of the teat** (papilla mammae). The **duct system** of each mammary unit can be subdivided into the following segments (Fig. 18-23):

- Terminal parts of the glands (glandular alveolus): place of milk production,
- Lactiferous duct (ductus lactiferi): system of ducts for the transport of milk,
- Lactiferous sinus (sinus lactifer): sinus for the bulk of milk.

The glandular tissue is arranged in lobules (lobuli glandulae mammariae), which comprise a multitude of alveoli, the actual sites of milk production and secretion. These alveoli are lined by a single-layered cuboidal epithelium and are separated from each other by interstitial septa that convey nerves and blood vessels. Several lobules are enclosed by thicker interstitial septa to form mammary lobes (lobi glandulae mammariae) (Fig. 18-23 and 24). (For a more detailed description see histology textbooks.)

The milk drains to an **intralobular duct** that joins others to form a **larger interlobular duct.** Interlobular ducts lead to a system of lactiferous ducts that ultimately convey the milk to the relatively large **lactiferous sinus.** Each lactiferous duct

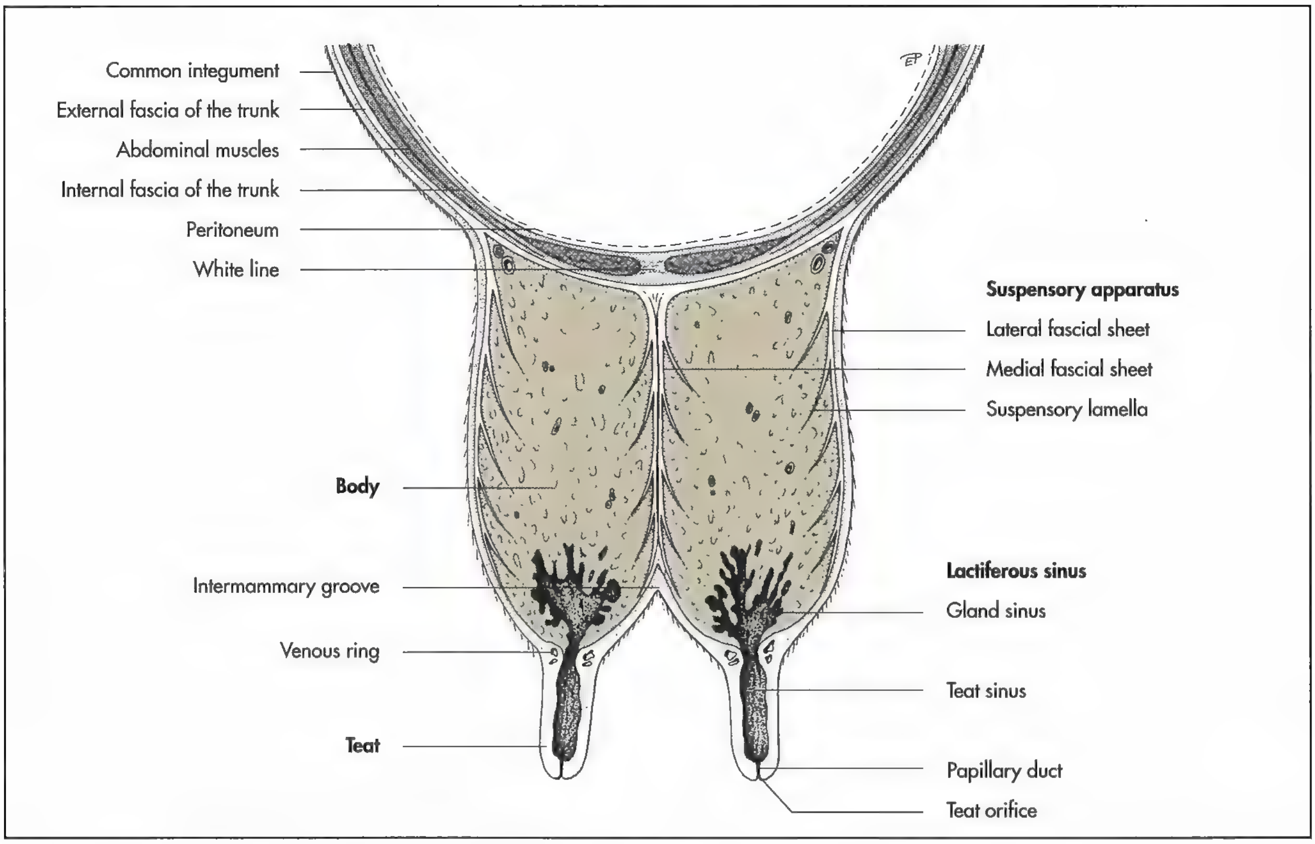


Fig. 18-22. Suspensory apparatus of the udder, schematic (Dyce, Sack and Wensing, 1991).

is responsible for the drainage of a mammary lobe, while each intralobular duct drains one lobule.

The **lactiferous sinus** extends into the teat and is incompletely divided into the gland (pars glandularis sinus lactiferi) and the teat sinus (pars papillaris sinus lactiferi) by a constriction. The glandular part of the sinus has several chambers and a wide diameter. The transition between the gland part and the teat part is marked by a mucosal fold, that contains a venous plexus, which has to be taken into consideration when amputating a teat to avoid excessive blood loss. The **teat sinus** is continuous with the **papillary duct** or **teat canal,** which opens at the tip of the teat where the orifice is surrounded by a **smooth muscle sphincter.**

Blood supply

The mammary glands receive their blood supply from the superficial blood vessels of the ventral body wall (Fig. 18-29, 30 and 31).

Arteries

The thoracic and the cranial abdominal mammary complexes receive their arterial blood supply from the mammary branches of the **cranial superficial epigastric artery** (Fig. 12-20), a perforating branch of the **internal thoracic artery.** Segmental ventral intercostal branches of the internal thoracic artery may also contribute blood to the thoracic glands. The caudal abdominal and inguinal mammary complexes are supplied by mammary branches of the **caudal superficial epigastric artery** that arises from the **external pudendal artery.**

Veins

The thoracic mammary complexes drain into the **cranial superficial epigastric veins,** that opens into the **cranial epigastric vein,** which in turn drains into the internal thoracic vein. The abdominal and inguinal mammary complexes drain into the **caudal superficial epigastric veins,** which open into the **external pudendal vein.** Of functional importance is the presence of anastomoses between the cranial and caudal superficial artery as well as between the like-named veins. The species-specific differences concerning the blood supply of the mammary glands will be discussed in detail when the gland of each species is described.

Lymphatic system

The lymphatics of the thoracic and cranial abdominal mammary complexes drain to the **axillary lymph node.** The lymphatics of the caudal abdominal and the inguinal mammary

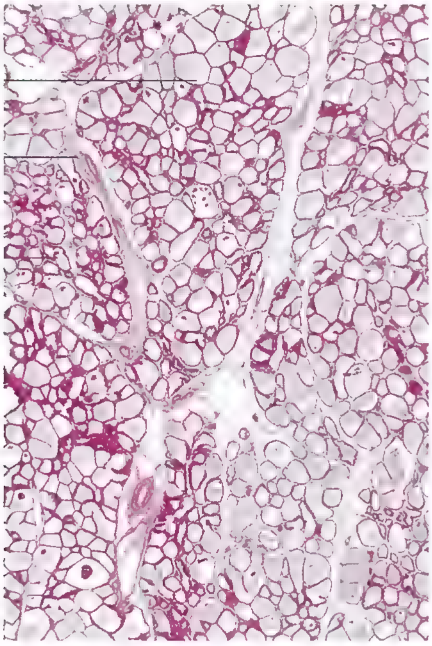


Fig. 18-23. Histological section of the glandular tissue of a bovine udder with alveoles and interstitium separating the lobules.

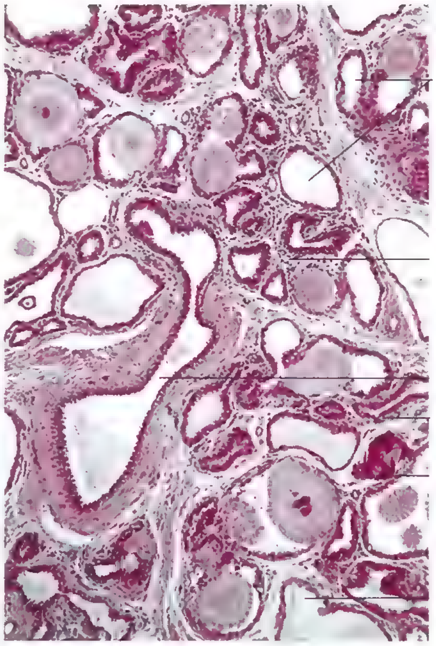


Fig. 18-24. Histological section of the glandular tissue of a bovine udder (Liebich, 2004).

complexes drain to the **superficial inguinal lymph node,** which is also called the **mammary lymph node.** This lymph node is located at the base of the inguinal mammary gland and is usually palpable under the skin. Since mammary tumours may metastasise to the draining lymph nodes, removal of these is routinely performed, when mammary tumours are surgically removed **(mastectomy).**

Innervation

The mammary glands receive **sensory, sympathetic and parasympathetic innervation.** The thoracic mammary glands are innervated by lateral and medial mammary branches of the cutaneous part of the intercostal nerves, which are also referred to as ventral branches of the thoracic nerves. The abdominal and inguinal complexes are supplied by the cutaneous branches of the **iliohypogastric, ilioinguinal** and **genitofemoral nerves.** The inguinal mammary glands receive additional innervation from the mammary branch of the distal cutaneous branch of the **pudendal nerve** and the **genitofemoral nerve.**

In addition to being subject to nervous control, secretion of the mammary glands is influenced by **hormones** from the hypophysis and other endocrine organs.

Neurohormonal reflex arc

The sensory nerve supply to the teats and the skin of the mammary glands constitutes the afferent part of the **neurohormonal reflex arc,** which is responsible for initiating and maintaining lactation. When the mammary glands are stimulated by suckling on the teats or massage of the skin, the sensory nerve fibres conduct the impulses to the central nervous system. These impulses trigger the production of oxytocin in certain nuclei within the hypothalamus and its release into the blood stream via the **neurohypophysis. Oxytocin** causes contraction of the **myoepithelial cells** in the walls of the duct system within the mammary glands and the milk is "let down". The effect of oxytocin is antagonised by adrenaline, which is released under stress. (For a more detailed description see histology and physiology textbooks.)

Development of the mammary gland

Prenatal development of the mammary gland occurs in both sexes, while the further postnatal development occurs only in female individuals during puberty and pregnancy. The mammary gland is also referred to as the accessory gland of the female reproductive tract. Completion of development is influenced by female hormones, especially progesterone and prolactin and the mammary gland is only fully functional at the end of gestation.

The mammary glands develop as epithelial buds, that grow into the underlying mesenchyme from linear ectodermal thickenings, the **mammary ridges.**

Two different developmental mechanisms lead to the formation of teats: in ruminants and in the horse proliferation of the mesenchyme surrounding the epithelial buds, that later forms the mammary body, forms a raised teat upon the surface of the body. In carnivores and the pig the alveolar tissue proliferates and forms a so-called eversion teat, as it is characteristic for human beings. (For a more detailed description see embryology textbooks.)

Male and female mammary glands have small mammary bodies and short teats from birth until the first oestrus of females. The duct system consists of the teat canal, the **lactiferous sinus** and short epithelial outgrowths, which develop into

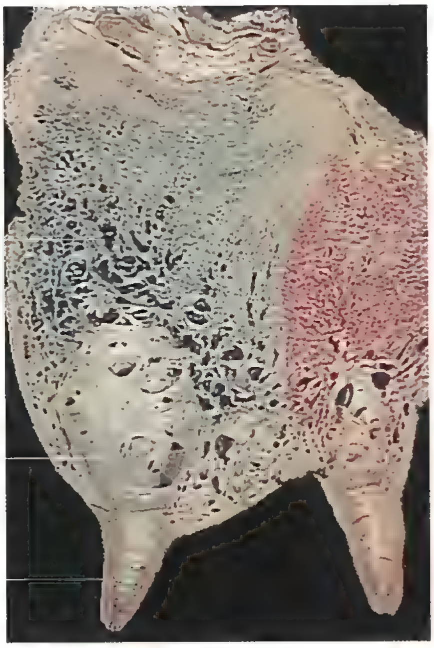


Fig. 18-25. Sagittal section of the glandular tissue of the cranial and caudal quarters of a bovine udder. The different colour indicating the complete separation of the individual quarter.

Fig. 18-26. Sagittal section of the teat (papilla mammae) of a cow.

Fig. 18-27. Sagittal section of the teat (papilla mammae) and papillary duct (ductus papillaris) of a bovine udder.

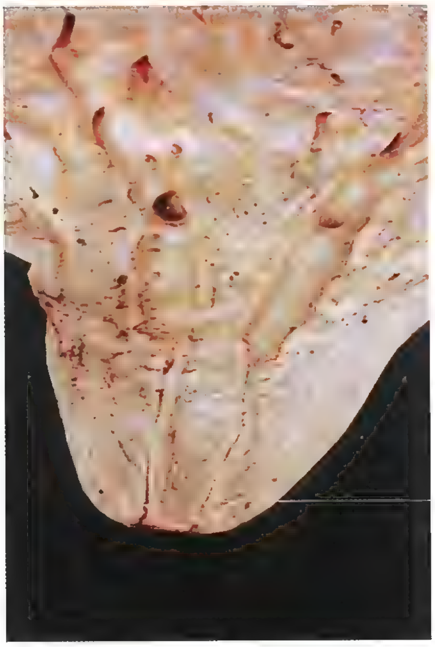


Fig. 18-28. Sagittal section of the teat (papilla mammae) of an equine udder with two papillary ducts (ductus papillares).

the **lactiferous ducts.** During puberty, the production of oestrogen by the ovaries in female individuals causes the connective tissue stroma to proliferate and the lactiferous ducts to develop further. They branch out to form smaller ducts. Further development does not occur until first pregnancy.

Shortly after conception the development of the duct system restarts and new generations of lactiferous ducts are formed by division and growth of the epithelial outgrowths. In the second half of pregnancy glandular tissue is formed and starts to replace the connective tissue stroma. At this stage parts of the alveoles are still solid and canalise later at the end of pregnancy under the influence of progesterone, oestrogen and prolactin. The first milk produced is called colostrum and is rich in protein, containing a high number of **immunoglobulins,** which provide the new-born with a **passive immunity.** The colostrum is also thought to have a laxative effect, important for defecation of the meconium shortly after birth.

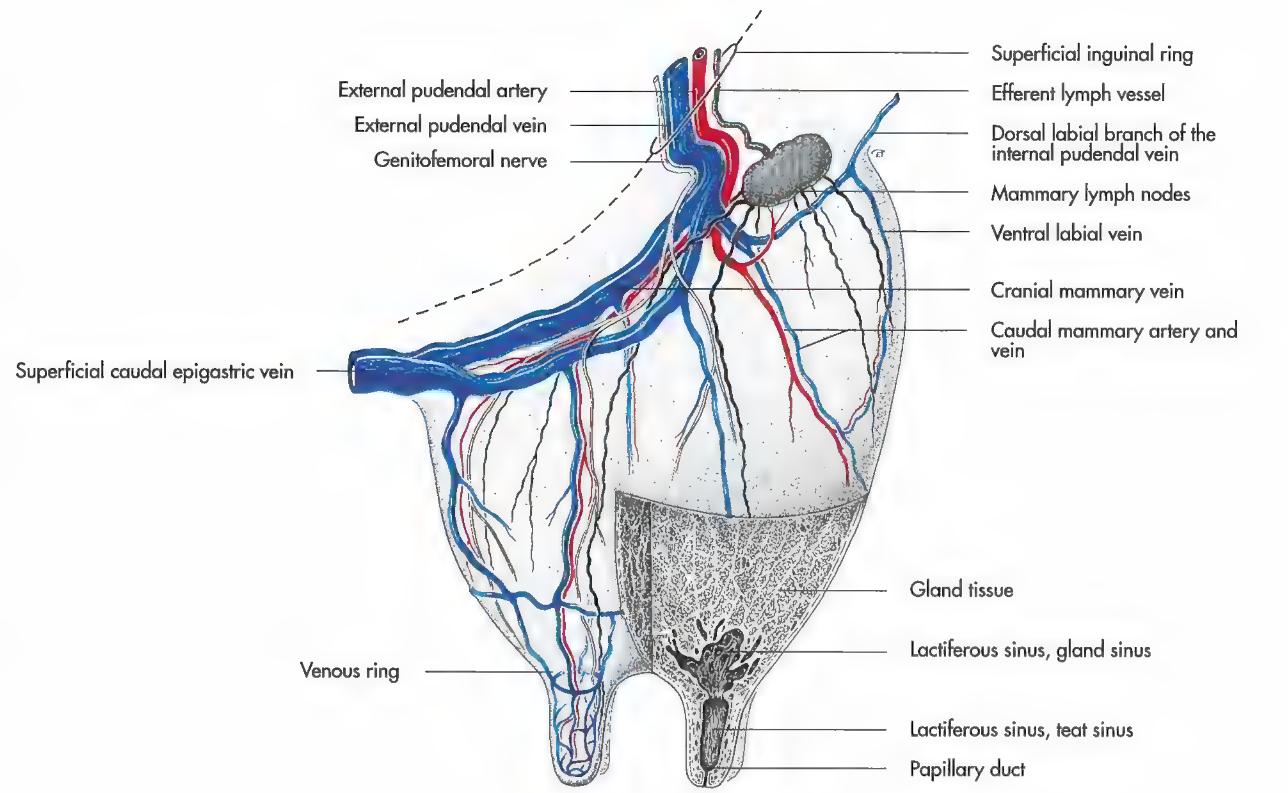


Fig. 18-29. Innervation and blood supply of the bovine udder, schematic (Ellenberger and Baum, 1943).

Mammary buds also form in male embryos and persist to give rise to the rudimentary teats found on the ventral surface of the trunk in carnivores and pigs or on the cranial surface of the scrotum in ruminants and less common beside the prepuce in horses. Some male individuals with an unusual high oestrogen level the mammary glands undergo postnatal changes, similar to those in females.

Lactation

Milk secretion may start hours or even days before parturition and is used as an indicator of impending parturition. Postnatal production and secretion of milk is continued only by those mammary complexes, which are stimulated by suckling of the new-born. Suckling at the teat and massage of the mammary body with paws or tongue initiates the **neurohormonal reflex arc,** that lead to the let down of the milk. Mammary complexes that are not stimulated soon undergo involution. Mammary glands are fully developed and fully functional only at the height of lactation. They are then large and show a predominance of glandular tissue over the connective tissue stroma.

When the dam weans her young or stimulation of the mammary glands is stopped, involution commences and the milk-producing tissue regresses. Glandular tissue is replaced by connective and fatty tissue. However, the gland never reverts to its prelactation size.

Mammary glands (mamma) of carnivores

In the bitch the mammary gland typically comprises **ten mammary complexes,** arranged in two bilaterally symmetrical rows, that extend from the ventral thoracic to the inguinal region (Fig. 18-20). However the formation of the mammary gland is not always symmetrical and the number of complexes varies from eight to twelve. The mammary complexes are termed according to their position: **thoracic, cranial abdominal, caudal abdominal** and **inguinal complexes.**

The cat commonly has **eight mammary complexes,** also arranged in two symmetric rows, extending from the ventral thorax to the abdomen.

Each mammary complex consists of between **five** and **twenty mammary units** with a corresponding number of papillary ducts, that open on the tip of the teat with a separate **opening** (ostium papillare).

The juvenile, non-lactating mammary complexes are inconspicuous with short teats, while during lactation the single mammary complex increases considerably in size and has then a semi-spherical form. Its size varies among breeds and even among individuals. Shallow grooves indicate the border

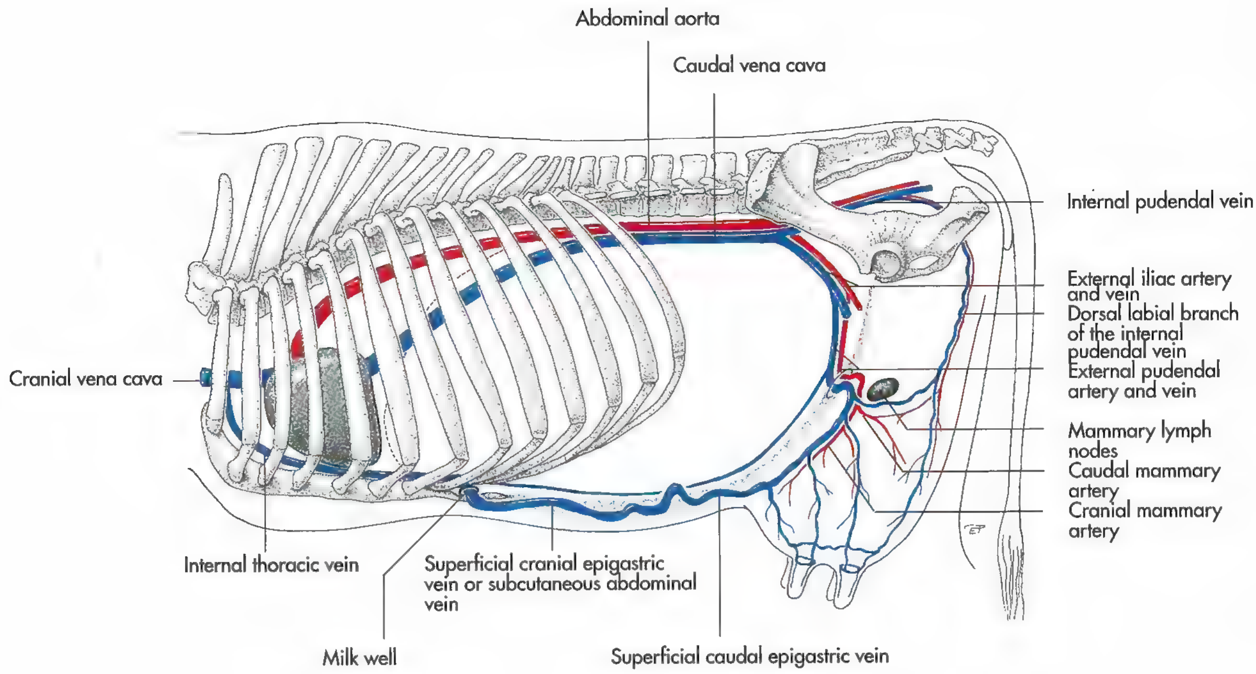


Fig. 18-30. The most important blood vessels supplying the bovine udder, schematic.

between the complexes. A distinct **intermammary sulcus** divides the right from the left row.

The changes characteristic for the sexual cycle of the bitch include growth and proliferation of the mammary gland with each cycle, even when the bitch does not conceive. The frequent proliferation and subsequent involution of the mammary gland is thought to be a predisposing factor for the high incidence of mammary tumours in the bitch.

The mammary glands of carnivores receive additional blood supply from the mammary branches of the **lateral thoracic artery.** Lymph from the cranial thoracic mammary complex does not only drain to the **axillary lymph node,** but may also drain to the **superficial cervical lymph node.** Lymph from the cranial abdominal mammary complex can either drain to the axillary or the superficial inguinal lymph node, while lymph from the caudal abdominal complex may also drain to the medial iliac lymph nodes. **Interconnection** of the left and right superficial inguinal lymph nodes is described. A good understanding of the lymphatic flow is of clinical importance with regards to metastases in the case of mammary tumours.

Mammary glands (mamma) of the pig

The mammary gland of the pig usually comprises **14 mammary complexes,** arranged in two rows on the ventral side of the thorax and abdomen (Fig. 18-20). In most animals the left and right complexes are not at the same transverse plane, but are arranged in an alternating manner. This arrangement facilitates access of the piglets, when the sow is lying on the side. Each complex consists of **two or three mammary units.** Each unit opens with a separate orifice at the tip of the teat in a shallow depression. If the depression is too deep the suckling piglet compresses the opening and interrupts the flow of milk.

At the height of lactation the mammary gland of the sow is quite conspicuous and the single hemispherical complex has the size of a fist with relatively short teats. Those complexes that are not used by the piglets are much smaller than lactating units. This gives the mammary gland an irregular appearance.

The thoracic mammary complexes receive additional blood supply from the mammary branches of the **lateral thoracic artery.** Sufficient milk production at the height of lactation is essential for the proper weight gain in the piglets in the first few weeks of life, thus posing an important economic factor in the pig industry.

Udder (uber) of small ruminants

In the ewe and nanny-goat the mammary gland is restricted to the inguinal region and comprises **two mammary complexes,** one on each side of the ventral midline (Fig. 18-20). Each complex consists of a **single mammary unit,** the duct system of which opens in a single orifice on the tip of the teats.

In the ewe lymph may drain directly into the iliofemoral and the medial iliac lymph nodes.

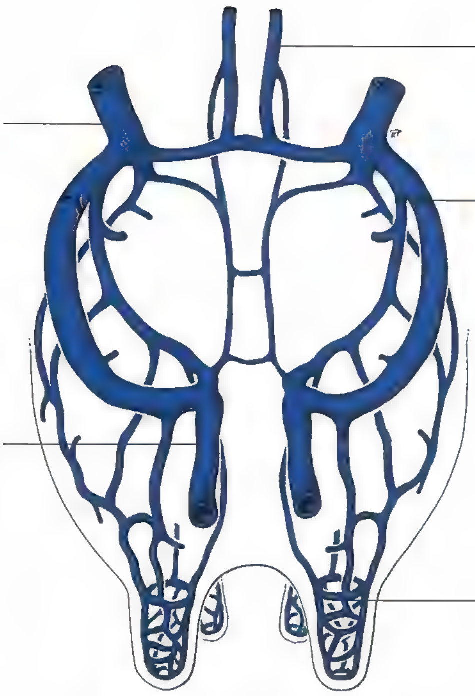


Fig. 18-31. Venous drainage of the bovine udder, schematic (Najbrt, 1982).

Bovine udder (uber)

The mammary gland of the cow comprises **four mammary complexes,** with a single unit each, that are consolidated in a single mass, the udder. The udder is suspended from the inguinal region by its suspensory apparatus (Fig. 18-21). It is divided into quarters that correspond to the **four units,** each of which bears one of the principal teats with a single opening. Accessory teats, sometimes associated with functional glandular tissue are very common they are undesirable, since they may complicate milking, when they are fused or too close to the principal teats. Inflammation of superfluous glandular tissue can spread to the main quarters and lead to a decrease in milk production.

A prominent median **intermammary groove** marks the division of the udder into **right** and **left halves.** The boundary between the **fore-** and **hindquarters** of the one side is not distinct. It is of clinical importance that the **four mammary glands** are **separate units.** Thus, inflammatory processes can be restricted to one quarter. Local antibiotics must be administered in each teat separately.

The **appearance of the udder** varies greatly, depending on breed, maturity and functional status. In many dairy cows, the udder is extremely large with very long and thick teats (Fig. 18-27). However, size is not a reliable indicator for productivity, but certain features of conformation are of practical importance with regards to milking. Size, shape, position of the teats and the form of the teat extremity are an especially important factor. Open teat canals predispose the quarter to ascending infections, while a narrow teat canal may lead to obstructions and an impaired milk flow. The lipid and protein components of the mucosa of the teat canal constitutes a natural barrier against bacterial infections.

To match the high productivity of today's dairy cow, the udder receives a very generous blood supply. It is estimated that some 600 litres of blood must flow through the udder for every litre of milk secreted. The main blood vessels are very wide in diameter.

The **main artery** to the udder is the direct continuation of the **external pudendal artery.** It enters the base of the udder on its dorsocaudal aspect after passing through the inguinal canal. It first forms a sigmoid flexure before dividing into a **cranial** and **a caudal mammary artery** (Fig. 18-30). The two mammary arteries anastomose with the **superficial caudal epigastric artery,** which enters the organ on its cranial side and is connected to the **cranial epigastric artery** (Fig. 12-20 and 21). The **internal pudendal artery** also detaches a branch to the udder (ramus labialis dorsalis et mammarius), which enters the organ caudally (Fig. 18-30).

Drainage of the udder is effected by the external pudendal veins, which lead through the inguinal canal and the **superficial cranial epigastric veins,** which pursue flexuous subcutaneous courses over the ventral abdominal wall. In large animals, the superficial cranial epigastric vein is also called the **subcutaneous abdominal ("milk") vein,** which has a strikingly tortuous course, a varicose structure and **incompetent**

Fig. 18-32. Footpads of a dog.

Fig. 18-33. Chestnut proximomedial to the carpus of a horse as rudimentary carpal pad (torus carpeus).

valves. The opening of this vein through the body wall (the "milk wall") is readily identified on palpation. The milk vein can be used for intravenous injection or blood sampling. The anastomosis between the cranial and caudal superficial vein enlarges considerably during the first pregnancy. With the vastly increased flow of blood through them, the veins become congested, their tributaries engorged and their valves progressively broken down.

Additional venous drainage is achieved by the **dorsal labial vein** (also called the caudal mammary vein, in contrast to the caudal superficial epigastric vein, which is also called the cranial mammary vein), which drains into the internal pudendal vein (Fig. 18-29, 30 and 31).

Equine udder (uber)

The mammary glands of the horse are consolidated in a relatively small udder in the inguinal region. A distinct intermammary groove separates **left** and **right halves.** Each half has the form of a laterally compressed cone and carries a single teat. Each half comprises a **single mammary complex,** which in turn consists of **two mammary units.** The two duct systems open on the tip of the teat with two separate openings (Fig. 18-28). The skin over the udder is thin, deeply pigmented and sparsely haired. The teats are short and resemble a bilaterally compressed cylinder.

The tissues of the individual units of each side interdigitate, but the duct systems are completely separate. Sebaceous secretion, epithelial debris and colostrum that escapes during the last days of pregnancy give the extremity of the teat a waxy appearance and is used as an indicator of impending parturition.

Clinical terms related to the mammary gland:
Mastitis, mastectomy, mammography.

Foot pads (tori)

S. Reese

The foot pads are formed by strongly modified common integument and are found in the fore- and hindlimbs. They act as shock absorbers during locomotion and protect the skeleton of the manus and pes from mechanical pressure. The base of the foot pads is formed by the digital cushions, which are made of subcutaneous adipose tissue, that is partitioned by reticular, collagenous and elastic fibres. Retinacular fibres extend from the dermis into the subcutis and anchor the foot pads to the fascia of the manus or pes. Well-developed ligaments fasten the metacarpal and metatarsal pads to the skeleton.

To withstand the considerable mechanical forces the papillary body of the dermis is especially well-developed. The epidermis of the foot pads forms an especially thick, soft and elastic horn layer.

There are **three groups** of foot pads:

- Carpal/tarsal pads (torus carpeus/tarseus) on the mediopalmar/-plantar aspect of the carpus/tarsus,
- Metacarpal/metatarsal pads (torus metacarpeus/ metatarseus) on the palmar/plantar aspect of the metacarpo(tarso)phalangeal joint,
- Digital pads (torus digitalis) on the palmar/plantar aspect of the third distal phalanx.

The number of the **metacarpal/metatarsal** and **digital pads** corresponds to the number of digits. In ungulates only the digital pads are functional and in contact with the ground, in which they are incorporated in the hoof, providing the features known as the bulb in ruminants and pigs, the frog and

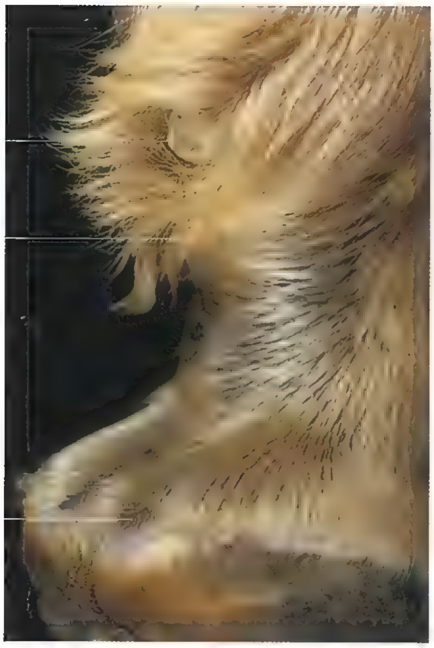


Fig. 18-34. Ergots (calar metacarpeus) as rudimentary metacarpal pads (torus metacarpeus) and heel bulbs (torus ungulae).

Fig. 18-35. Bulbs of the principal and accessory hoofs of a pig.

heels in the horse. Digital pads are found on the third and fourth digit in ruminants and on the second to fifth digits in pigs. These structures are described in detail later in this chapter. The horse, unlike the other domestic ungulates, also has rudimentary metacarpal/tarsal pads embedded in a tuft of hair behind the fetlock joint, the ergot and vestigial carpal/tarsal pads, the chestnuts (Fig. 18-33 and 34).

In the digitigrade dog and cat, only digital and metacarpal/tarsal pads make contact with the ground. There are fully developed carpal pads of no obvious use, but no tarsal pads in the cat and dog. The metacarpal / metatarsal pads of the second to fourth digit of each foot are fused to form a single pad (Fig. 18-32). Digital pads are found on each digit of the dog and cat, however, the pad of the first digit does not make contact with the ground (Fig. 18-32). The foot pads of the cat and dog contains eccrine sweat glands, which causes the animal to leave paw prints, when sweating.

The digit (organum digitale)

K.-D. Budras, Chr. Mülling und S. Reese

The digit comprises the distal phalanx, including musculoskeletal components and the strongly modified part of the common integument, that encloses those structures.

In adaptation to the different environments and eating habits, **three basic class-specific modifications of the skin** of the organum digitale developed during evolution:

- Claw (unguicula) in carnivores,
- Nail (unguis) in primates,
- Hoof (ungula) in ungulates.

Function

Nails, claws and hooves serve primarily to protect the tissue they enclose, but secondarily each is also used for other purposes, such as:

- Tools: scratching, digging, holding,
- Sensory organs,
- Weapons.

Their importance during locomotion differs among species. The cat is able to withdraw the claws in a skin fold during locomotion thus protecting the claw from overuse. In the horse, being perissodactyles, the part of the hoof that contacts the ground, correspondes to the rim of the fingernail in humans.

Segmentation

Although the structures enclosing the distal phalanx appear to be quite different at first glance, they share in fact a similar architecture. Each of these appendages presents five different segments (Fig. 18-36):

- Perioplic segment (limbus),
- Coronary segment (corona),
- Wall segment (paries),
- Sole segment (solea) and
- Footpad (torus digitalis/ungulae), that corresponds to the digital bulb of primates.

The **segments are distinguished** by their location, structure and horn production. Characteristic features are the presence or absence of a subcutis, the form of the papillary body and

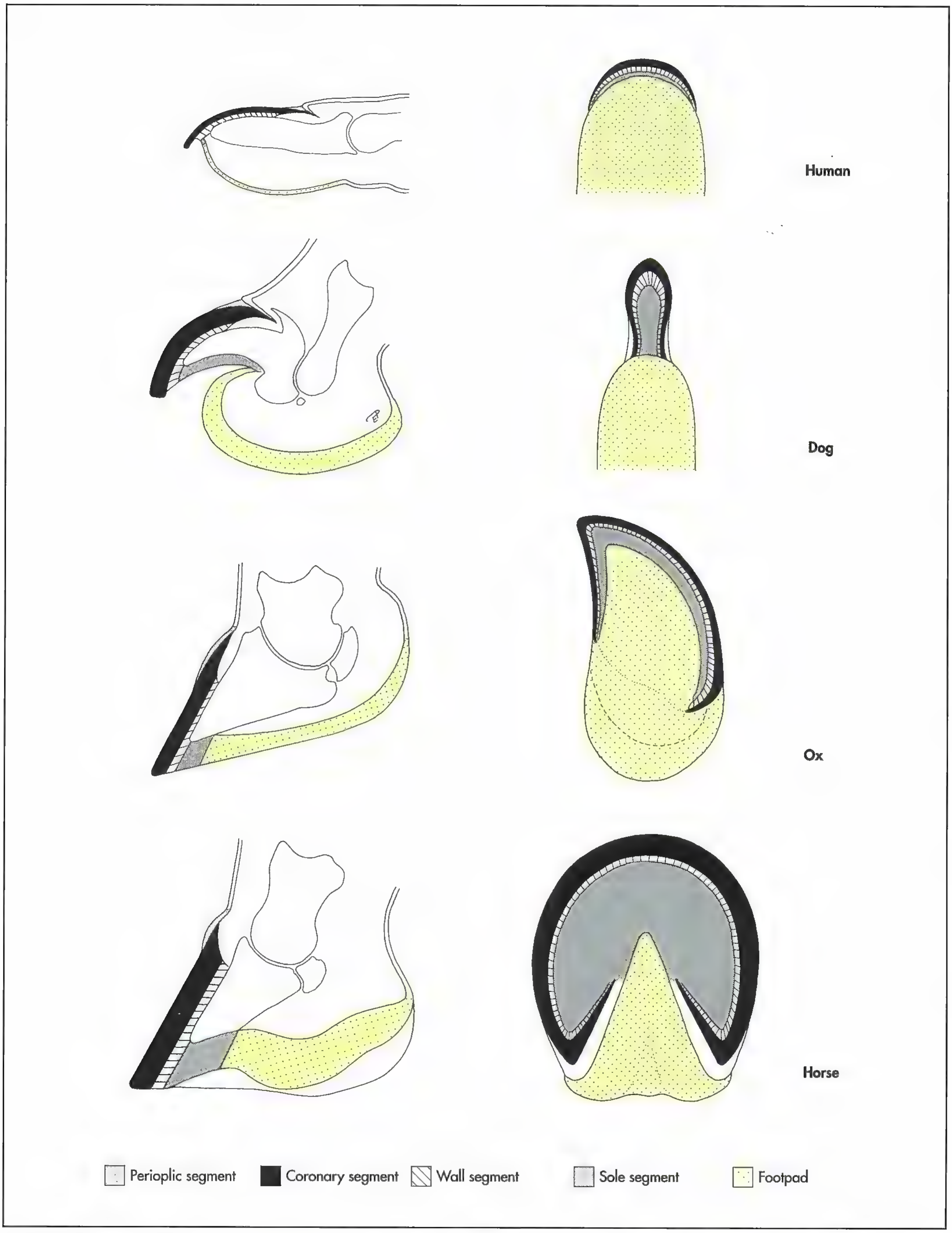


Fig. 18-36. Segmentation of nail, claw, bovine and equine hoof, sagittal section and ground surface, schematic (Zietzschmann, 1918, and Mülling, 1993).

Fig. 18-37. Sagittal section of the horn shoe of a horse.

the **structure of the stratum corneum** (type of cornification, architecture of the horn). However these characteristics vary strongly between species and are described later in this chapter in detail (Fig. 18-36). Even if the segmentation is not clear from the outside, it is possible to determine the different segments on a longitudinal section or after removal of the horn capsule.

Fig. 18-38. Section of the wall of a horn shoe.

Horny enclosure of the distal phalanx (capsula ungularis)

The distal phalanx of the domestic mammals is enclosed by a horny capsule, which forms the claw of carnivores and the hoof of ungulates. All five segments participate in the formation of the hoof capsule, while the foot pad is not part of the claw in carnivores, but remains separate.

The **horn capsule** can be divided into two parts (Fig. 18-37):

- Wall (paries corneus, lamina),
- Ground surface (facies solearis).

Wall (paries corneus, lamina)

The wall is formed by the perioplic segment, coronary segment (corona) and the wall segment (paries) and corresponds to the nail of primates. It consists from the outside to the inside of following layers (Fig. 18-38):

- External layer (stratum externum, eponychium),
- Middle layer (stratum medium, mesonychium),
- Internal layer (stratum internum, hyponychium).

Ground surface (facies solearis)

The ground surface is formed by the **distal part of the wall,** that contacts the ground, the sole segment and the footpad of ungulates.

The internal stratum of the wall, that appears on the solar surface is termed the **white line** and forms a **flexible layer,** that unites the horn of the wall and the sole.

The sole can be further subdivided into those parts, that **contact the ground** (facies contactus) and those parts, that **do not contact the ground** (facies fornicis) (Fig. 18-39). The distribution and extension of these two parts varies considerably between species.

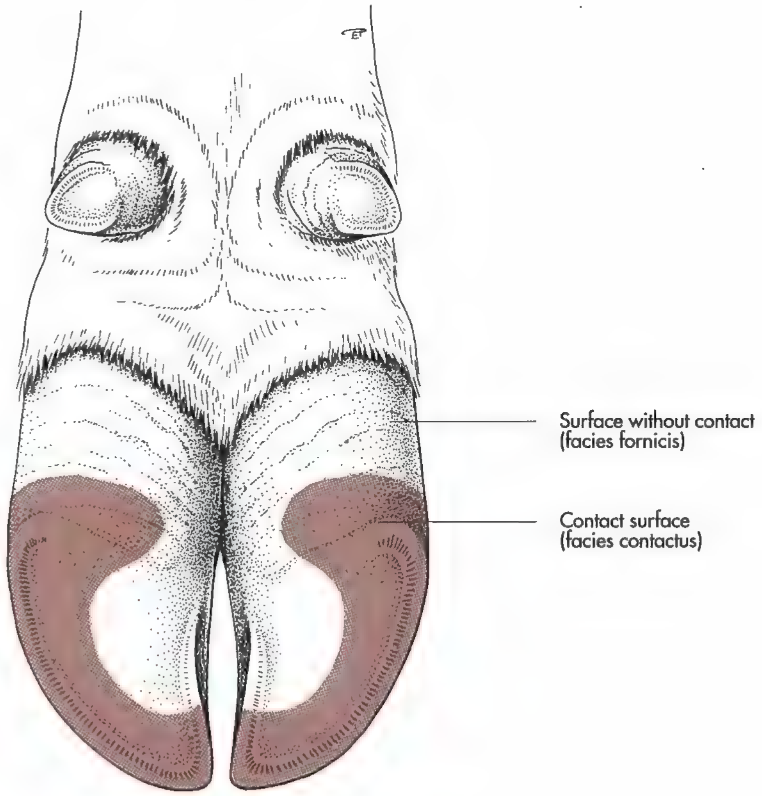


Fig. 18-39. Palmar surface (facies solearis) of the hoof of cattle, with weight bearing (facies contactus) and non-weight bearing (facies fornicis) parts, schematic (Clemente 1979).

Deciduous horn shoe (capsula ungulae decidua)

The hoof of new-born piglets, calves, lambs and foals are covered by a **deciduous horn capsule,** which is especially well-developed in the sole and foot pad (Fig. 18-40). It is light yellow in colour and consists of incompletely cornified epithelial horn. It has a high water content, an elastic structure and rounded contours. Corresponding to the permanent capsule it is formed by the same five segments.

The deciduous horn capsule covers the hoof like a cushion, thus protecting the uterus and birth canal from injuries during parturition. During the first few days post partum it rapidly dries out and falls off when the animals start walking. The permanent horn capsule is already completely formed beneath the deciduous one.

In the new-born puppy or kitten the pointed and sharp claw is also cushioned by an incompletely cornified epidermis. A corresponding structure is found on the nail of new-born babies. Modifications of the dermal layers in the different segments

The origin of the different segments of the nail, claw and hoof as local modifications of skin are reflected in their retention of epidermal, dermal and subcutis layers. However, the degree and extension of modification varies greatly between the different segments.

Subcutis (tela subcutanea)

No subcutis is present in the **wall** and **sole segment,** where a stable, mechanical union between the dermis and the distal phalanx is essential. Underlying the limbus, coronary segment and foot pad is a thick, **resilient subcutis** (pulvinus), an admixture of collagenous and elastic fibres interspersed with adipose tissue and cartilagenous islets. These structures act as shock absorbers during locomotion.

Dermis (corium)

The dermis of the distal phalanx is also referred to as **pododerma.** Corresponding to the layers of the skin it can be further subdivided into a **deep papillary** and a **superficial reticular layer.** In those segments, where no subcutis is developed the dermis is tightly adherent and continuous with the **periosteum** of the underlying bone.

The surface of the papillary layer is characteristic of each segment. In all segments other than the wall segment, the papillary layer forms **dermal papillae** (papillae dermales), which either protrude directly from a plane underlying surface or are elevated on low-profile laminae (Fig. 18-41). The length of the papillae varies in the different segments and among species. In the horse, for example the papillae of the

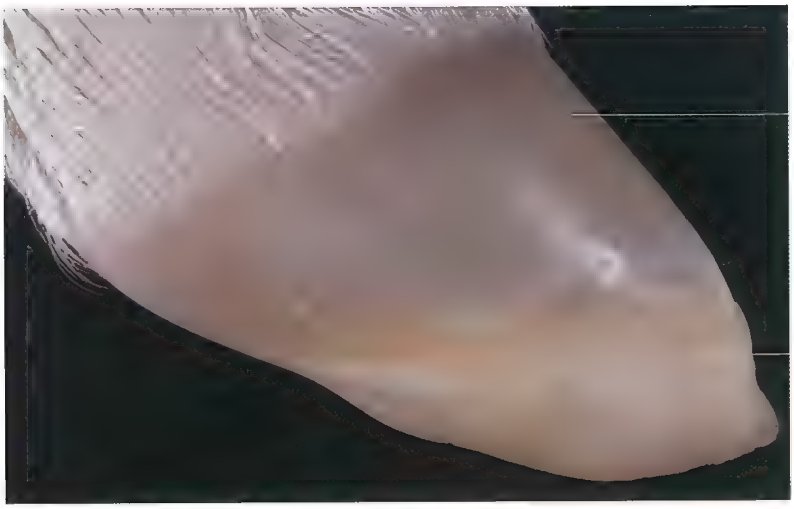


Fig. 18-40. Deciduous horn shoe (capsula ungulae decidua) on the distal end of the permanent horn shoe (capsula ungulae) in a maturec-equine foetus (courtesy of PD Dr. H. Bragulla, Berlin).

coronary segments can reach a length of 8mm. In the wall segment the surface of the papillary layer is marked by **parallel lamellae** (lamellae dermales), extending from proximal to distal in the hoof and arranged in a curve way in the claw. Small papillae extend from the tip of the laminae.

Epidermis

The epidermis can be divided in a thin part formed by living, cornified cells and a thicker part of cornified cells. The vital layers comprise the basal layer (stratum basale), spinous layer) stratum spinosum and granular layer (stratum granulosum), while the horn consists of the **horny layer** (stratum corneum) only.

Vital layers of the epidermis

The cells in the vital layers of the epidermis undergo the same changes as in the skin, which gradually leads to their **keratinization** and **cornification.** Keratin proteins and membrane coating material are synthesised within all cells, but the composition varies between the different segments. Cornification of the soft type takes place in the perioplic segment, the foot pads and the terminal epidermis of the wall segment, where a granular layer is present. In the remaining segments, there is no granular layer and the cells undergo the hard type of cornification, resulting in a mechanically resilient horn.

Horn (stratum corneum)

The **stratum corneum** consists of densely packed completely **keratinised cells.** During the process of keratinization and cornification, the epidermal cells undergo a series of internal changes that gradually bring about their death and when reaching the horny layer they are incapable of further division or growth. Horn cells are moved distally by cells from deeper layers moving towards the surface. The horn cells, are held together by membrane coating material, thus the structure of horn can be compared with a brick wall: the cells being the brick, the membrane coating material the mortar.

Horn quality and **fastness** are characteristic of each segment and depend on the amount and composition of the keratin and the membrane coating material. Desquamation of the horn starts with loss of function of the membrane coating material followed by the disintegration of the cell aggregates.

Coronary horn is **extremely durable** and is worn down mechanical loading. If not worn down, it needs to be trimmed away. Sole horn, however, lasts only a short time. This accounts for the fact that the sole horn, which fills the ground surface between wall and frog in the hoof of the horse is concave.

Structure of the horn-cell-junction

In all segments the surface structures of the dermis interdigitate with the inner layers of the epidermis. In those segments, where the dermis forms **papillae** (papillae dermales), the vital layers of the epidermis are arranged in **tubules** (tubuli epidermales), which form the horn tubules embedded in **intertubular horn** (Fig. 18-41). If the dermis is arranged in laminae, the epidermis also forms **horny laminae,** which interdigitate with the underlying **laminar dermis.**

Tubular horn

Tubular horn consists of **horn tubules,** which are embedded in less structured **intertubular horn.** Horn tubules have a **cortex** and a **medulla.** The cortex is formed by the **peripapillary epidermis** located on the sides of the dermal papillae, while the medulla is formed by the **suprapapillary epidermis** on the end of the dermal papillae. Cortical horn cells keratinise under optimal circumstances, since their peripapillary position provide them with a short distance for nutritional molecules. These cells are very stable and durable. Keratinization of medullary horn cells is often incomplete

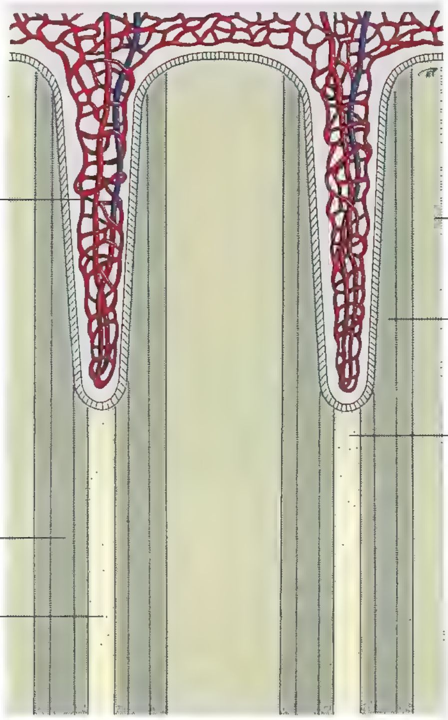


Fig. 18-41. Development of epidermal tubular horn over a papillary dermal matrix, schematic.

and these cells disintegrate after a short time, leaving the lumina of the horn tubules empty. Thus the horn tubules are in fact hollow cylinders, which fulfils the mechanical principle of a stable and at the same time lightweight arrangement. **Intertubular horn** is formed between the dermal papillae and consists of **isometric horn cells.**

Due to its design, **tubular horn** is extremely pressure resistant. Horn tubules of hooves keep their form over the whole length, which can be up to 10cm from the coronary segment to the sole. In the claw, the tubular horn of the coronary segment is deformed into laminar horn distally.

Functions of the horn

The horn encloses the distal phalanx and fulfils a variety of functions. Its mechanical stability allows loading of the limb during locomotion and prevents injuries to the distal phalanx. The horn also controls the **loss** and **absorption of water.** Its quality is largely influenced by the water content. Too much or too little water leads to a deterioration of quality and loss of elasticity. Horn acts as a **thermal insulator.** It constitutes a barrier against ascending **microbes,** the medullary cells of the horn tubules being the weakest link. Ascending infections can lead to a painful inflammation of the dermis. In animals which stand on damp bedding the integrity of the horn is often disrupted and microbes gain access to deeper structures. Urine and faeces dissolve the membrane coating material and urea is known to selectively destroy the proteins within the horn cells. Some diseases such as **laminitis** or **canker** lead to the development of dyskeratotic horn of minor quality. This horn is characterised by a low keratin content and dysfunctional membrane coating material and is thus prone to bacterial disintegration.

Horn quality differs largely between individuals. It is genetically determined, but is also influenced by **diet,** with zinc and biotin playing an important role. Impairment of vascular supply to the dermis, as seen in animals that are not worked at all or over-worked, may also result in the production of horn of minor quality.

Claw (unguicula)

K.-D. Budras

The digital organs of carnivores comprise the **digital pad** and the **claw,** which extends apically from the pad. While some authors apply the term "claw" to the horny enclosure only, others include the enclosed musculoskeletal structures.

Canine claw

Corresponding to the number of digits, the dog possesses **five claws in the forelimb** and **four claws in the hindlimb.** The first digit in the forelimb is reduced and has no contact to the ground. If not trimmed, the claw may continue to grow in a circular fashion until the point of the claw invades the volar furrow between the base of the claw and the foot pad or the foot

Fig. 18-42. Claw (unguicula) and digital pad (torus digitalis) of a dog (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-43. Ground surface of the claw of a dog (courtesy of PD Dr. S. Reese, Munich).

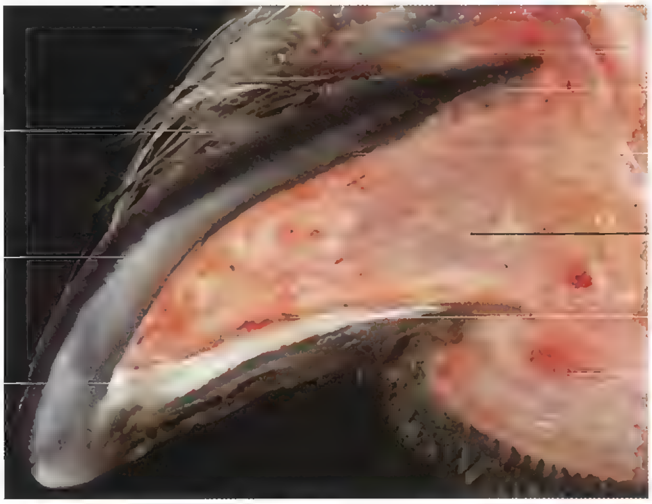


Fig. 18-44. Sagittal section of the claw of a dog (courtesy of PD Dr. S. Reese, Munich).

pad itself. In the hindlimb, a reduced first digit or **"dewclaw"** without skeletal components may be present below the tarsus on the medial aspect of the paw. It is often removed routinely from young puppies, however it must be retained in puppies of certain breeds (e.g. St. Bernards) if there is the possibility that they will later be used for showing.

Form of the claw

The claw is curved and follows the shape of the unguicular process of the distal phalanx. It can be compared to a human nail, which has been laterally compressed. On gross examination, it presents a sole, two walls and a central dorsal ridge. It is oval to round in diameter and the sharpness of the tip depends on its wear (Fig. 18-42, 43 and 44).

Segments of the claw

The claw of the dog can be divided into four segments from proximal to distal: **Perioplic, coronary, wall** and **sole segment** (Fig. 18-36). The horn produced by these segments forms the wall and sole of the claw (Fig. 18-44). The perioplic segment and the coronary segment are not visible on the surface, but fit within the space under the ungual crest of the distal phalanx.

This relationship is hidden by the skin of the claw fold. Dorsally, this fold is a modification of the hairy skin, which is free from hair on one side and fused to the horn of the claw. The perioplic, coronary and wall segments form the walls and the dorsal border of the claw, which are connected to the underlying unguicular process of the distal phalanx. The sole covers the ventral surface of the unguicular process and the horn appears as a crumbly whitish material between the edges of the wall.

Perioplic segment (limbus)

The perioplic segment forms the most proximal part of the claw and is adjacent to the inside of the **unguicular crest** (Fig. 18-44). The papillary projections on the surface of the dermis are rather indistinct and the horny layer of the epidermis consists of non-tubular, soft horn on the outside of the wall of the claw. It forms the external layer (stratum externum), that corresponds to the thin glossy layer formed by the periople in the horse and is worn away long before it reaches the distal end of the claw (Fig. 18-44).

Coronary segment (corona)

The coronary segment occupies the **floor of the claw fold** (Fig. 18-44). The coronary dermis carries distinct papillae, which can reach a length of up to 0.7mm and may take their origin from the dermal laminae. The horn formed by the coronary dermis is arranged in tubules at its origin, but looses its tubular structure distally. It forms the middle layer (stratum medium) of the claw wall, which is thicker dorsally than laterally.

Wall (paries)

The wall segment is in direct contact with the **unguicular process of the distal phalanx.** Its dermis is arranged in lamellae, the height of which ranges from 5 μm proximally to 0.3 mm distally. The epidermis of the wall segments interdigitate with the dermal lamellae, but does not cornify centrally. Thus, the horn formed by the wall segment does not have laminar form, but in fact has a tubular structure, produced by the terminal papillae. Cornification is of the soft type and includes a granular layer. The resulting tubular horn is rubber-like, lighter in colour than the coronary horn and disintegrates distal to the papillae (Fig. 18-43).

Sole (solea)

The narrow sole segment is adjacent to the palmar/plantar aspect of the ground surface (facies solearis) of the unguicular process extending from the flexor tuberosity to the apex. Its dermal papillae are directed apically and increase in length and number from proximal to distal. Unlike the sole epidermis of the hoof, the sole epidermis of the claw forms a non-tubular, soft, crumbly horn by **soft cornification** (Fig. 18-43). It disintegrates, when the claw is removed and the isolated claw is typically open between the walls.

Digital pad (torus digitalis)

The digital pad is located proximal to the sole segment of the claw, but is not integrated within the claw itself as it lies in the hoof. It is described in detail earlier in this chapter.

Blood supply

Claw and digital pad receive a **generous blood supply,** which accounts for the fact that wounds in this region tend to bleed heavily (Fig. 18-45 and 46). Arterial blood supply is provided by four arteries, which run dorsoaxial, dorsoabaxial, palmo(planto)axial and palmo(planto)abaxial on each digit. They are termed according to the same principle on all four digits. For the fourth digit of the thoracic limb their names are:

- Axial proper dorsal digital artery IV (a. digitalis dorsalis propria IV axialis),
- Abaxial proper dorsal digital artery IV (a. digitalis dorsalis propria IV abaxialis),
- Axial proper palmar digital artery IV (a. digitalis palmaris propria IV axialis) and
- Abaxial proper palmar digital artery IV (a. digitalis palmaris propria IV abaxialis).

The **palmar (plantar) arteries** detach branches (rami tori digitales) to the digital pad and a coronary branch (a. coronalis) to the coronary segment. These arteries pass to the sole foramen of the distal phalanx and anastomose to form the terminal arch. Several arteries extend into the dermis of the claw. The smaller dorsal arteries extend to the unguicular crest. The **veins** are satellites of the arteries and are named like-wise.

Fig. 18-45. Arteriogram of the paw of a dog, dorsopalmar projection (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-46. Arteriogram of the paw of a dog, lateromedial projection (courtesy of PD Dr. S. Reese, Munich).

Lymphatic drainage

Lymph from the digits of the thoracic limb drains into the superficial cervical lymph node, lymph from the pelvic limb to the popliteal lymph node.

Innervation

Thoracic limb

Sensory innervation to the first digit and the dorsal aspect of the second to fifth digit is provided by the radial nerve. The palmar aspect of the second to fifth digit is innervated by branches of the ulnar and median nerves.

Pelvic limb

The first digit and the medial (abaxial) aspect of the second digit are innervated by the saphenous nerve. Innervation of the dorsal aspect of the second to fifth digit is provided by the fibular nerve, while innervation of the plantar aspect, including the digital pads is provided by the tibial nerve. Pain receptors are integrated into the periosteum of the unguicular process and can be stimulated with a sharp instrument to test sensation during a neurological examination.

Feline claw

The anatomy of the feline claw follows that of the canine claw with some **species-specific exceptions.** The claw of the cat is laterally compressed, strongly curved and drawn out to a sharp point. It resembles a sickle, with a sharp inside curve and a blunt convex surface (Fig. 18-47). Unlike dogs, cats use their claws as weapons and for initial prey contact. The characteristic "clawing" on trees, logs, furniture etc. is performed to sharpen the claws and to mark their territory by sweat from the glands in the digital pads. Unlike the claw of the dog, the claws of the cat can be actively and fully retracted by **elastic ligaments into the claw fold.** This enables the cat to walk silently and without blunting the claws through ground contact.

Blood supply

Blood supply to the claw of the cat is in principle identical to that to the claw of the dog.

Lymphatic drainage

Lymph of the thoracic limb drains to the axillary lymph node, lymph of the pelvic limb to the popliteal lymph node.

Fig. 18-47. Claw of a cat, lateral aspect (courtesy of Dr. S. Reese, Munich).

Innervation

Thoracic limb

Like the dog, sensory innervation of the first digit is provided by the radial nerve, which also supplies the dorsal aspects of the second to fourth digit. Branches of the radial nerve may extend on the palmar aspect of these digits up to the level of the digital pad. The palmar aspect of the second to fourth digit is innervated by the median nerve, while the fifth digit is completely innervated by the ulnar nerve.

Pelvic limb

Innervation to the digits of the pelvic limb of the cat is in principle identical to that of the dog.

Hooves (ungula) of ruminants and pigs

Chr. Mülling

Ruminants and pigs are classified as **artiodactyles,** indicating that they possess two weight-bearing digits on each foot. Similar to the claws of carnivores and the hoof in horses the distal phalanx is enclosed in a horny modification of the skin, the hooves. While the general anatomy of the hooves of these species follow the same principle, there are several species-specific characteristics. With regards to the phylogenetic development, the hooves of the artiodactyles have to be classified between the claw of carnivores and the hoof of the horse. They are regarded as a special form of the **hooves of ungulates,** but are paired in contrast to the single hoof of the horse.

Diseases of the hooves, e.g. laminitis, are common in cattle and play an important role in herd-health. Together with fertility problems and diseases of the udder, they account for considerable financial losses to the dairy and meat industry. A good understanding of the anatomy and function of the hoof is a necessary prerequisite for successful prophylaxis, e.g. correct trimming, and treatment of claw disease.

Definition

The term **"hoof"** is sometimes used for the horny enclosure of the distal phalanx only, while in other contexts it includes the horny appendage as well as the enclosed musculoskeletal structures. The latter definition is more appropriate, since all these structures form a functional unit. It comprises (Fig. 18-49):

- the distal part of the middle phalanx (os coronale),
- the distal interphalangeal joint (articulatio interphalangea distalis) with its ligaments,
- the distal phalanx (os ungulare),
- the distal sesamoid (navicular) bone (os sesamoideum distale),
- the terminal portion of the digital flexor tendons, that insert onto the flexor tubercle and extensor tendon, that insert onto the extensor process of the distal phalanx,
- the navicular bursa (bursa podotrochlearis) between the navicular bone and the deep digital flexor tendon.

Bovine (ungula) hooves

Each limb has **two principal hooves** and **two dewclaws.** The principal digits (third and fourth digit) carry the principal hooves, which are seperated from each other by the **interdigital space.** The dewclaws are carried by the rudimentary second and fifth digit. They are considerably smaller than the principal digits and in most cases comprise a middle and distal phalanx only. They are attached to the proximal phalanx of the neighbouring principal digit by soft tissue. They do not make ground contact, thus do not wear off and require regular trimming (Fig. 18-48, 49 and 51).

Fig. 18-48. Hoofs of the thoracic limb of an ox (courtesy of PD Dr. S. Reese, Munich).

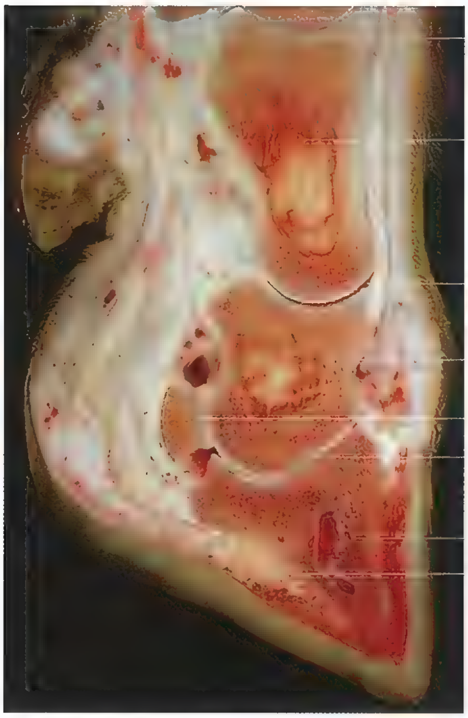


Fig. 18-49. Sagittal section of the lateral principal and dewclaw of the thoracic limb of an ox (courtesy of PD Dr. S. Reese, Munich).

Form of the hooves

The **hooves of the thoracic limb** are more rounded than those of the pelvic limb and have a wider interdigital space. The angle of the dorsal wall is about 50–55° in the front and 45–50° in the back. The lateral hoof carries the greater share of the weight and is usually larger than the medial one, although this is not always the case in the hindlimb.

The **wall of the hoof** follows the shape of the distal phalanx and forms a **concave axial part** towards the interdigital space (pars axialis), a **convex abaxial part** (pars abaxialis) and rounded **dorsal roof** (margo dorsalis) (Fig. 18-48). The sole or ground surface of the hoof (facies solaris) is relatively flat, with a concave area axially, that does not make ground contact. It is bordered by the inflected angle of the wall and blends with the apex of the bulb centrally (Fig. 18-39). The hooves grow continuously and if not worn off, require regular trimming.

Functions

The horny enclosure protects the digit from **mechanical, chemical** and **biological influences** of the environment. Its resistance against chemical and biological agents is of special importance, when many animals are confined to a relatively small area, the flooring is not ideal and aggressive substances are constantly in direct contact with the hoof.

The hoof acts as **shock absorber** during locomotion. The forces that the limb is subjected to are cushioned and diverted. The digital pads are incorporated within the hoof and their thick subcutis form the bulb of the hoof. The pads act as cushions on which the animal walks. It is complemented by the elastic epidermis, with which it forms a functional unit. Another shock-absorbing mechanism is the possibility of the hooves of the same limb to **move apart,** when the foot contacts the ground. However the **distal interdigital ligament** limits this movement to a physiological degree. The attachments of the epidermis of the hoof to the distal phalanx divert the forces onto the skeletal structures. It is similar to the hoof mechanism in horses, but not as effective. In cattle 40–60% of the sole and bulb contact the ground, while in the horse only the rim of the sole, the frog and the bulbs contact the ground. In non-domestic animals, hooves are also used for digging, scraping and as weapons.

Segments of the hoof

Corresponding to the claw of carnivores and the hoof of the horse, the hoof of artiodactyles can be divided into several segments. Segmentation is based on the architecture and organisation of the modification of the layers of the common integument. The following **five segments** can be distinguished (Fig. 18-50 and 51):

- Perioplic segment (limbus),
- Coronary segment (corona),
- Wall segment (paries),
- Sole segment (solea) and
- Digital pad or bulb (torus ungulae).

Macroscopically the different segments can be separated most easily by looking at the surface of the dermis after removal of the epidermal horny hoof capsule.

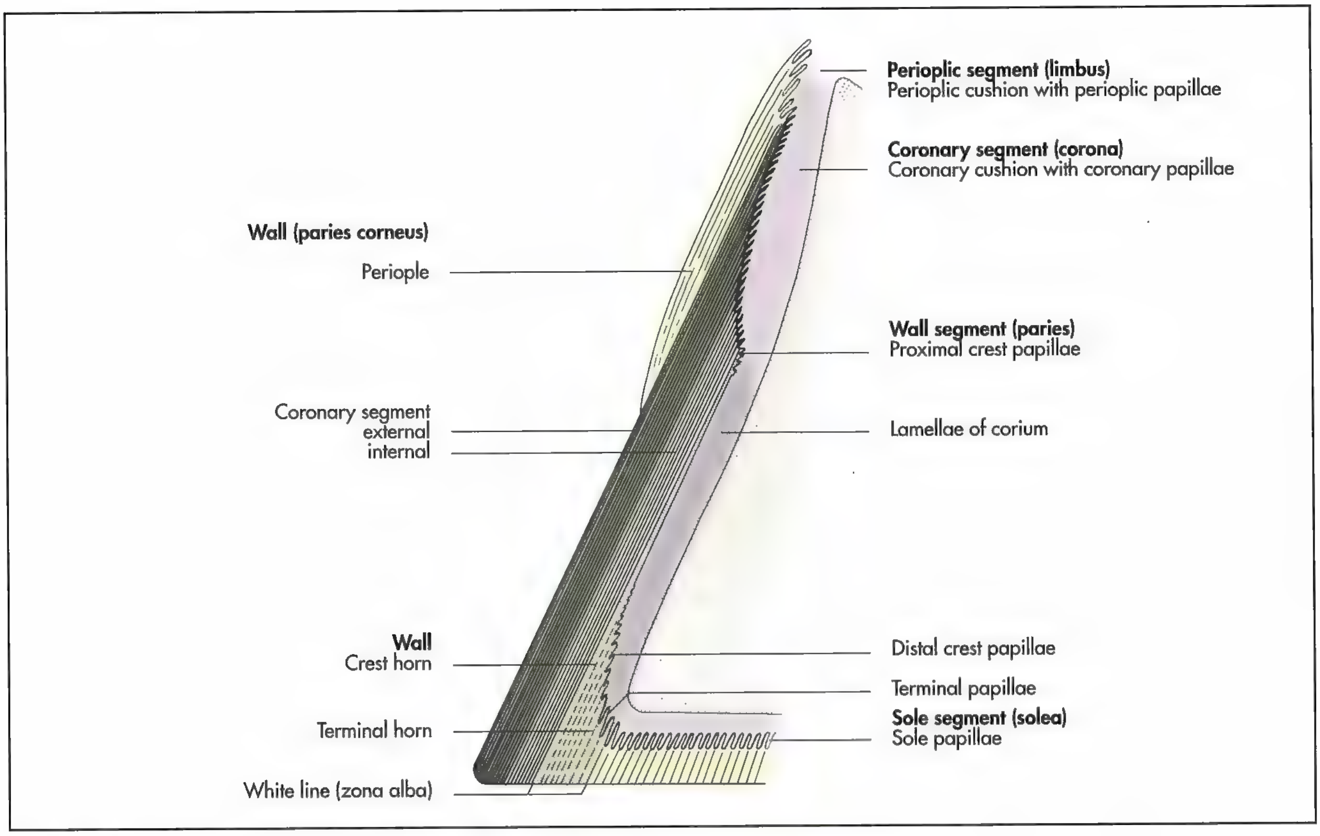


Fig. 18-50. Perioplic, coronary, wall and sole segment of the principal bovine hoof, schematic.

Perioplic segment

Abaxially the periople is directly adjacent to the hairy skin, while it merges with the periople of the other principal hoof axially. It provides a narrow strip (about 1cm) dorsally, that widens palmarly and plantarly.

The **underlying subcutis** (tela subcutanea limbi) of the periople is thickened to form the slightly protruding perioplic cushion (pulvinus limbi) dorsally and axially. This thickening broadens palmarly and plantarly, where it merges with the bulb (Fig. 18-50 and 51).

The **perioplic dermis** (dermis limbi) is divided abaxially from the hairy skin by a shallow groove, while the border towards the coronary segment is marked by a crest, which is especially distinct abaxially. This crest is characteristic for the bovine hoof. The surface of the perioplic dermis carries 1-2 mm long, narrow papillae, that are directed distally.

The **perioplic epidermis** (epidermis limbi) has a tubular structure. The soft, crumbly horn produced by the epidermis slides distally over the coronary segment and is worn off rapidly and covers only the proximal third of the hoof wall (Fig. 18-50). It is thought to have a function in the regulation of the water content of the proximal hoof segments.

Coronary segment

The coronary segment extends from the perioplic segment distally to about the middle of the hoof wall. It is about 2.5 cm wide dorsally and narrows to about 1–1.5 cm axially and to about 0.5 cm abaxially (Fig. 18-50). The coronary subcutis is modified to from the slightly protruding **coronary cushion** (pulvinus coronae).

The **coronary dermis** (dermis coronae) carries delicate papillae with conical endings. They are orientated perpendicular to the surface of the dermis at their origin, but gain a distal orientation later.

The **coronary epidermis** (epidermis coronae) corresponds to the surface of the coronary dermis by forming delicate horn tubules. Their diameter is largest in the middle part of the coronary segment, smaller to the outside and very small or with no horn tubules in the innermost layer.

The extremely hard and resistant coronary horn constitutes the middle layer of the wall of the hoof, thus contributing the largest part of the hoof (Fig. 18-50 and 52). The distal part of the coronary horn help form the outer part of the sole (margo solearis).

The **coronary horn** is marked by prominent ridges that run parallel with the coronary border. On the palmar/plantar aspect of the hoof the coronary horn is covered by the bulb horn (Fig. 18-51). The coronary horn has distinct grooves towards the interdigital space.

The **coronary epidermis** forms the **hardest horn** of the bovine hoof, which is twice as hard as the coronary horn of the equine hoof. The coronary grows about 4–8 mm per month, depending on breed, age and nutrition.

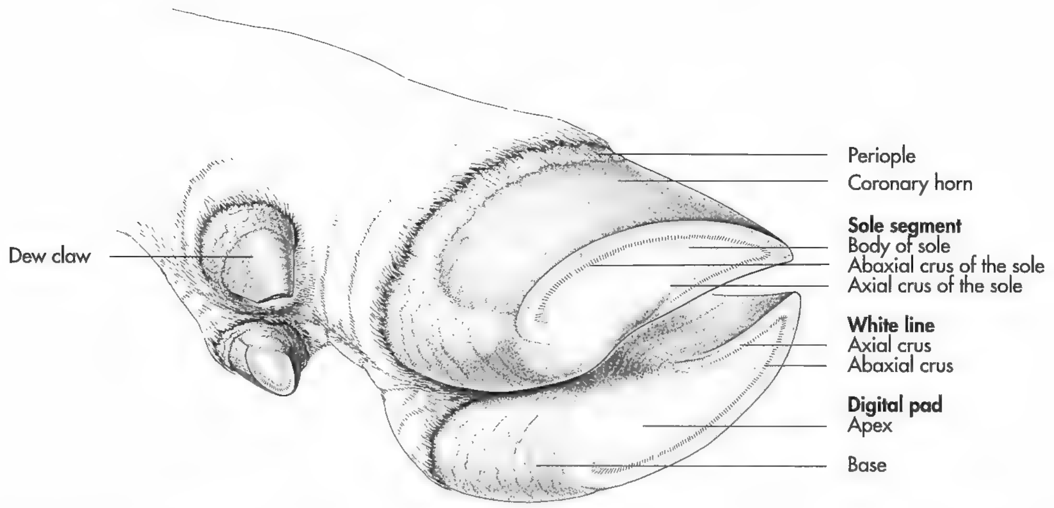


Fig. 18-51. Ground surface (facies solearis) of the principal hoofs and the dewclaws of the ox, showing the white line (zona alba), schematic.

Wall segment

The wall segment is covered by the **thick coronary horn,** which forms distally. It is bordered proximally by the coronary horn and extends distally to the sole, where it forms a sharp lateromedial inflection, which is less distinct on the palmar/plantar aspect than dorsally (Fig. 18-50). The wall segment joins the wall to the sole and is visible on the sole as the white line (zona alba) (Fig. 18-51). There is no subcutis developed in the wall segment and the dermis is directly adherent to the periosteum of the underlying bone.

The **dermis of the wall segment** (corium parietis) has a laminar structure. Unlike in the hoof of the horse the laminae (lamellae dermales) do not carry secondary lamellae, but carry very delicate, short, hook-shaped papillae on the crest of their distal third. Some papillae are also present in the proximal third of the lamina. The terminal parts of the laminae takes a sharp turn towards the sole and merge with the sole dermis. They carry long, distinct terminal papillae on their endings.

The **epidermis** (epidermis parietis) of the wall segment forms **laminae** (lamellae epidermales), that interdigitate with those of the dermis (Fig. 18-52). Only the centre of the epidermal laminae is originally cornified. The interdigitating arrangement of the epidermis and dermis and the lack of a subcutis provides a very resistant junction between the horn of the hoof and the distal phalanx. Since the forces, the bovine hoof are submitted to are considerably less than those of the equine hoof, no secondary lamellae have developed.

Moulded on the crest and terminal papillae of the dermis, the epidermis forms **tubular horn** around these structures. These horn formations are called crest or terminal horn respectively, which are part of the **white line** (Fig. 18-50).

Latest research results have shown, that the epidermis of the wall segment is characterised by a high growth rate, which is made possible by the increase in surface through the development of papillae. This contradicts the former belief, that the epidermis of the wall does not contribute to horn formation.

White line (zona alba)

The horn of the sole is separated from that of the wall by the so-called **white line** (Fig. 18-51). It is part of the wall segment and consists of the **laminar horn** and the **tubular horn** formed by the epidermis over the crest and the terminal papillae. The spaces between the proximal lamina are filled by crest horn in the wall region, while the terminal horn fills the distal space between the laminae towards the sole (Fig. 18-50). The composition of the epidermal horn by **three different horn structures** results in the three-layered appearance of the white line. The outermost, thin layer is adjacent to the coronary horn and is easily distinguished from the surrounding horn by its lighter colour. The middle part of the white line is formed by the horn laminae and the crest horn filling the spaces between the laminae. The terminal horn fills the spaces between the distal ends of the laminae towards the sole and forms the innermost layer of the white line.

The **width of the white line** is determined by the height of the horn laminae and is about 4–5mm in the tip of the toe. Due to the alternating arrangement of crest and terminal horn the white line appears to have stripes. The crest and terminal horn of the white line tends to crumble away, especially in animals, in which hoof-care is neglected. The resulting spaces provide an area of weakness, permitting access for microbes to the white line, which can lead to an in infection of the dermis.

The white line of the hooves of artiodactyles can be divided into an **axial** and an **abaxial part** (Fig. 18-51). The axial part extends from the apex of the hoof palmarly/plantarly following a concave course parallel to the margin of the sole. Its

Fig. 18-52. Horn shoe of an ox, part of the apaxial wall removed (courtesy of PD Dr. S. Reese, Munich).

terminal part courses towards the margin and finally arches axially and dorsally in the middle of the sole surface to end at the junction of the coronary, wall and bulb segment. The abaxial part follows a convex course along the margin of the sole to deflect axially for about 5–8 mm into the bulb segment.

Sole segment

The sole segment is confined within the white line on the sole surface of the hoof. It consists of a **body** (corpus soleae) and **two narrow crura** (crura soleae axiale et abaxiale), which extend from the body palmarly/plantarly. These crura end shortly before the termination of the axial and abaxial parts of the white line (Fig. 18-36 and 51).

The sole segment forms a **flat surface** and contributes to the weight **bearing surface of the hoof** (Fig. 18-39). Centrally the sole blends imperceptibly with the apex of the bulb. On visual and palpatory observation no distinction between the horn of the sole segment and the bulb segment is possible. Microscopically they are easily distinguished by the absence of a subcutis in the sole segment.

The **sole dermis** is characterised by low laminae, which are in direct continuation with the deflected ends of the laminae of the wall segment. The laminae carry long, stout papillae, that are arranged in rows and show a 40° inclination towards the toe.

The **epidermis** forms horn tubules corresponding to the dermal papillae, with a strikingly large diameter. These large tubules are visible macroscopically in the well-trimmed hoof. The growth rate of the hard sole horn is low and horn migrates slowly towards the toe, following the orientation of the dermal papillae.

Digital pad or bulb segment

The bulb provides the caudal part of the hoof and complements the sole segment in forming the ground surface of the hoof, where its apex insets into the crura of the sole segment. It is the chief weight bearing part. Palmarly/plantary it is bordered by haired skin. Based on structure and function, the bulb can be divided into **proximal** (pars proximalis) and **distal parts** (pars distalis). The proximal part is also called **base** (basis tori), the distal part apex of the **bulb** (apex tori) (Fig. 18-51).

The **base of the bulb** extends from the hairy skin to an imaginary line drawn between the ends of the axial and abaxial part of the white line. It forms the non-weightbearing palmar/plantar part of the bulb and the part of the weight-bearing ground surface. Axially it is adjacent to the non-hairy skin of the interdigital cleft and at the end of the axial part of the white line to the perioplic, coronary and wall segment. Abaxially it is bordered from proximal to distal by the perioplic, coronary and wall segment.

The **apex of the bulb** inserts into the crura of the sole and reaches the apically located body of the sole(Fig. 18-51).

The **subcutis** (tela subcutanea tori) is modified to form the **well-developed digital cushion** (pulvinus digitalis). The digital cushion consists of a mixture of collagenous and elastic fibres interspersed with adipose tissue. It is thickest (about 2 cm) beneath the proximal part of the bulb, where it extends over the whole width of the bulb. Its thickness gradually decreases towards the toe, where it measures about 5 mm, when it reaches the sole segment (Fig. 18-49). Its multi-chambered structure complements the elastic horn of the bulb in functioning as shock-absorber.

The **dermis of the bulb segment** (dermis tori) forms low laminae, which carry small papillae. They are not linear in the proximal part and follow a wave-like course. In the distal

Fig. 18-53. Arteriogram of the pelvic digits of an ox, dorsoplantar projection (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-54. Arteriogram of the pelvic digits of an ox, lateromedial projection (courtesy of PD Dr. S. Reese, Munich).

part they are higher and show a linear arrangement. Strong, **cone-shaped papillae** (papillae coriales) project perpendicular from the dermis and are arranged in whorls. In the distal part, they show a more apical inclination. The **epidermis of the bulb** (epidermis tori) forms tubular horn. The horn tubules differ in form, diameter, arrangement and inclination. In the proximal part cornification follows the soft type and the resulting horn has an elastic rubber-like consistency.

The **surface of the horn** is marked by fissures, which are especially distinct in animals, in which hoof care is neglected. **Bulbar horn grows** in layers and tends to flake, when allowed to build up. The multiple layered structure continues onto the interdigital wall and the coronary horn axially and the perioplic horn abaxially. The proximal part shows a considerable growth rate of up to 12 mm per month. If not worn-off as in animals stood on soft surface, the horn grows over the distal part of the bulb (sole horn overgrowth) and can lead to severe deformities. The deformed hoof leads to an overload of certain structures, such as the flexor tendons and to an increase in the load of the dermis, which is a predisposing factor in the aetiopathogenesis of pododermatitis.

The **cornification of the horn** of the distal part of the bulb follows the hard type and the resulting horn is considerably harder than the horn of the proximal part. The axial margin of the distal bulb does not contribute to the weight-bearing surface because of its slight concavity. The abaxial part is flat and contacts the ground on its whole length. In this area the parallel arrangement of the horn layers are indistinct.

Predisposed locations for diseases of the bovine hoof

Even in the well-cared hoof, there are certain locations, which are predisposed for diseases. Before deeper structures become affected, infectious agents must penetrate the horn layers. One of these predisposed sites is the border between the proximal and the distal part of the bulb, where horn of different resistance merge. Due to the different characteristics of the material, loading causes the formation of minute tears, which may act as starting points for larger fissures, that provide access to infection which may then destroy the dermis and deeper structures.

The white line is another point of weakness in the bovine hoof. The heterogeneity of the horn components and the wide tubular medulla predispose the white line to ascending infections **(e.g. white line disease).**

Blood supply

Arteries

The **main supply** to the hooves is provided by the palmar/plantar digital arteries of the two principal digits (aa. digitales palmares/plantares propriae axiales et abaxiales III et IV). They are complemented by the dorsal digital arteries (aa. digitales dorsales propriae axiales et abaxiales III et IV). The palmar digital arteries of the thoracic limb arise from the palmar

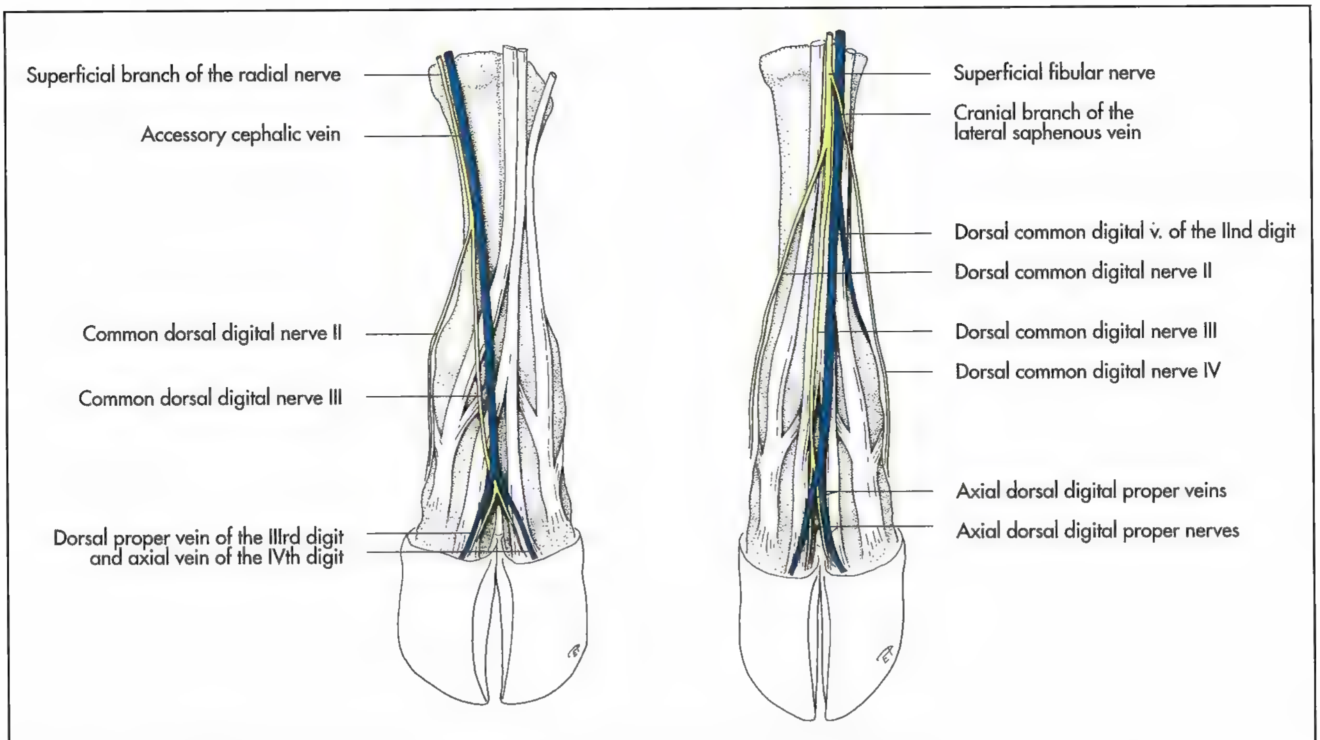


Fig. 18-55. Dorsal digital veins and nerves of the left thoracic and pelvic foot of an ox, schematic.

common digital artery III (a. digitalis palmaris communis III), the continuation of the median artery. In the pelvic limb, the plantar digital arteries arise form the plantar common digital artery III and receive blood from a branch (ramus perforans distalis III) of the dorsal metatarsal artery III (a. metatarsea dorsalis III).

The dorsal and plantar arteries are interconnected by interdigital arteries (aa. interdigitales).

The **smaller abaxial artery** passes to the bulbar region, where it extends 3–4 branches to the bulb (rami tori). These branch out and form an arterial network within the dermis of the bulb and the digital cushion. A larger palmar/plantar branch passes over the bulb distally to arborize in the sole segment. A coronary branch extends on the abaxial aspect of the bulb to the coronary segment, where it anastomoses with the coronary arteries. Another branch passes apically and supplies the dermis of the abaxial parts of the wall and sole segments. It anastomoses with branches of the terminal arch.

The **axial digital artery** is considerably larger than its abaxial counterpart. It follows the axial and dorsal contour of the hoof. Shortly after its origin, it detaches a branch to the **bulb** (ramus tori digitalis), which joins the branches of the abaxial artery in the formation of the bulbar arterial network. Further distal, the axial digital artery sends a larger branch to the **sole segment** (ramus palmaris/plantaris). At the level of the distal border of the middle phalanx arises the **coronary artery** (a. coronalis), which divides into deep and superficial branches to provide blood supply to the coronary segment.

The **axial digital artery** continues as the artery of the distal phalanx, which enters the distal phalanx on its axial surface. It extends almost to the apex of the distal phalanx, where it changes directions and turns back to the palmar/plantar end of the distal phalanx, and exits from the bone through the sole foramen. Within the bone the palmar/plantar abaxial and axial arteries anastomose to form the **terminal arch** (arcus terminalis) from which numerous branches are released. These branches form multiple anastomoses and leave the bone to provide the dermis of the wall and sole as well as parts of the coronary and bulbar dermis. From the terminal arch extends a stronger dorsal branch which anastomoses with the coronary artery.

Several arteries pass to the apex of the hoof and the margin of the sole, where they form arc-like **anastomoses** (a. marginis solearis).

This extensive arterial network guarantees an optimal supply to the dermis of the hoof from which the avascular dermis is supplied by diffusion.

Veins

Blood drains from the capillary beds into the **venous network** of the wall and sole dermis or in a separate superficial network. These networks are drained by a multitude of smaller veins, that open in the dorsal digital vein (v. digitalis dorsalis propria axialis) or in the **axial** or **abaxial palmar/plantar digital veins** (v. digitalis palmaris/plantaris propria III et IV axiales et abaxiales). The venous networks within the wall and sole dermis are drained via the abaxial and axial veins (Fig. 18-55).

The blood of the **superficial** and **deep networks** of the coronary region is drained by all three digital veins. The blood from the well-developed bulbar network is drained by numerous veins, which open into the abaxial digital palmar/plantar vein. One of the venous branches of the bulbar

Fig. 18-56. Thoracic foot of a sheep (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-57. Thoracic foot of a pig (courtesy of PD Dr. S. Reese, Munich).

segment anastomoses with the corresponding branch of the other hoof in the interdigital space. The rather indistinct venous network of the distal phalanx drains into the axial digital palmar/plantar vein. The veins of these networks are equipped with numerous valves.

The **complex venous system** of the hooves is of functional importance to maintain a well-balanced perfusion through the entire hoof. Venous valves and changing pressure promote backflow of the blood. Another important factor is the numerous anastomoses between the arterial and the venous side of the blood flow. **Venous drainage of the coronary border** is brought about by the axial and abaxial superficial coronary veins, which drain into the dorsal branch of the middle phalanx. This branch opens into the dorsal axial digital vein, that in turn drains into the common dorsal digital vein III.

The palmar digital axial vein III and IV open into the interdigital vein, an anastomosis between the common dorsal and palmar/plantar digital veins III.

Lymphatic drainage

Lymph from the hooves of the thoracic limb drains to the superficial cervical lymph node, while the lymph from the pelvic limb drains to the deep popliteal lymph node.

Innervation of the hooves

Thoracic limb

The palmar nerves of the foot are provided by the median nerve and by the palmar branch of the ulnar nerve. The dorsal nerves arise from the superficial branch of the radial nerve and the dorsal branch of the ulnar nerve (Fig. 18-55).

On the palmar aspect are three palmar common nerves, which all bifurcate at the level of the fetlock (metacarpophalangeal) joint. The palmar common digital branch III is often duplicated, but both branches unite on entering the interdigital space. There are three dorsal common digital nerves. The common dorsal digital nerve IV bifurcates at the dorsolateral aspect of the fetlock joint, the common dorsal digital nerve II on the dorsomedial aspect of the fetlock joint and the common dorsal digital nerve III bifurcates on entering the interdigital space.

The hooves of the thoracic limb are supplied by the following nerves and their branches:

Palmar nerves

- Palmar common digital nerve II (n. digitalis palmaris communis II),
- Axial palmar proper digital nerve II (n. digitalis palmaris proprius II axialis) for the dewclaw,
- Abaxial palmar proper digital nerve III (n. digitalis palmaris proprius III abaxialis) for the medial claw and the bulb,
- Palmar common digital nerve III (n. digitalis palmaris communis III),
- Axial palmar proper digital nerve III (n. digitalis palmaris proprius III axialis),
- Axial palmar proper digital nerve IV (n. digitalis palmaris proprius IV axialis),

- Palmar common digital nerve IV (n. digitalis palmaris communis IV),
- Abaxial palmar proper digital nerve IV (n. digitalis palmaris proprius IV abaxialis) and
- Axial palmar proper digital nerve V (n. digitalis palmaris proprius V axialis) for the lateral dewclaw.

Dorsal nerves

- Dorsal common digital nerve II (n. digitalis dorsalis communis II),
- Axial dorsal proper digital nerve II (n. digitalis dorsalis proprius II axialis),
- Abaxial dorsal proper digital nerve II (n. digitalis dorsalis proprius II abaxialis),
- Dorsal common digital nerve III (n. digitalis dorsalis communis III),
- Axial dorsal proper digital nerve III (n. digitalis dorsalis proprius III axialis),
- Axial dorsal proper digital nerve IV (n. digitalis dorsalis proprius IV axialis,
- Dorsal common digital nerve IV (n. digitalis dorsalis communis IV),
- Abaxial dorsal proper digital nerve IV (n. digitalis dorsalis proprius IV abaxialis) for the coronary and bulb segment of the lateral principal digit,
- Axial dorsal proper digital nerve V (n. digitalis dorsalis proprius V axialis) for the lateral dewclaw.

Pelvic limb

The plantar nerves of the hind feet are branches of the tibial nerve, the dorsal nerves are provided by the superficial and deep fibular nerve (Fig. 18-55).

Corresponding to the thoracic limb there are three dorsal and three plantar common digital nerves, which bifurcate proximal to the fetlock joint.

Plantar nerves

- Plantar common digital nerve II (n. digitalis plantaris communis II),
- Axial plantar proper digital nerve II (n. digitalis plantaris proprius II axialis) for the medial dewclaw,
- Abaxial plantar proper digital nerve III (n. digitalis plantaris proprius III abaxialis) for the medial hoof and bulb of the third digit,
- Plantar common digital nerve III (n. digitalis plantaris communis III),
- Axial plantar proper digital nerve III (n. digitalis plantaris proprius III axialis) for the interdigital space and the bulb of the third digit,
- Plantar common digital nerve III (n. digitalis plantaris communis III),
- Axial plantar proper digital nerve III. (n. digitalis plantaris proprius III axialis) for the interdigital space and the bulb of the third digit,
- Axial plantar proper digital nerve IV (n. digitalis plantaris proprius IV axialis) for the interdigital space and the bulb of the fourth digit,
- Plantar common digital nerve IV (n. digitalis plantaris communis IV),
- Abaxial plantar proper digital nerve IV (n. digitalis plantaris proprius IV abaxialis) and
- Axial plantar proper digital nerve V (n. digitalis plantaris proprius V axialis).

Dorsal nerves

- Dorsal common digital nerve II (n. digitalis dorsalis communis II),
- Axial dorsal proper digital nerve II (n. digitalis dorsalis proprius II axialis),
- Abaxial plantar proper digital nerve II (n. digitalis dorsalis proprius II abaxialis),
- Dorsal common digital nerve III (n. digitalis dorsalis communis III),
- Axial dorsal proper digital nerve III (n. digitalis dorsalis proprius III axialis),
- Axial dorsal proper digital nerve IV (n. digitalis dorsalis proprius IV axialis),
- Dorsal common digital nerve IV (n. digitalis dorsalis communis IV),
- Axial dorsal proper digital nerve V (n. digitalis dorsalis proprius V axialis) and
- Abaxial dorsal proper digital nerve IV (n. digitalis dorsalis proprius IV abaxialis) for the dorsolateral part of coronary and bulb segment of the fourth digit.

Hoof (ungula) of the small ruminants

The **basic anatomy of the hooves** of small ruminants is similar to that of the bovine hoof featuring the same segments. There are some species-specific differences with regards to the shape and structure of the hoof (Fig. 18-56).

The **angle of the wall** is steeper in small ruminants compared to cattle and measures about 50–70° in sheep and 60–70° in goats, depending on the breed. In relation to the length of the wall, the whole hoof is narrower. The wall is very thin, laterally compressed and sharply flexed upon itself forming a very narrow dorsal back of the hoof. The tip of the toe is bent inward towards the interdigital space, creating a concave axial and a convex abaxial surface. In animals in which hoof care is neglected, the horn of the wall overgrows the sole distally and turns back to grow over the ground surface.

The **horn of the wall,** especially in some goat breeds, is of harder consistency than that of cattle and results in very resistant hooves. The **subcutis of the perioplic** and **coronary segment** is modified to form a distinct pad on the abaxial side, especially in the goat.

Fig. 18-58. Foot of a horse, lateral aspect (courtesy of PD Dr. S. Reese, Munich).

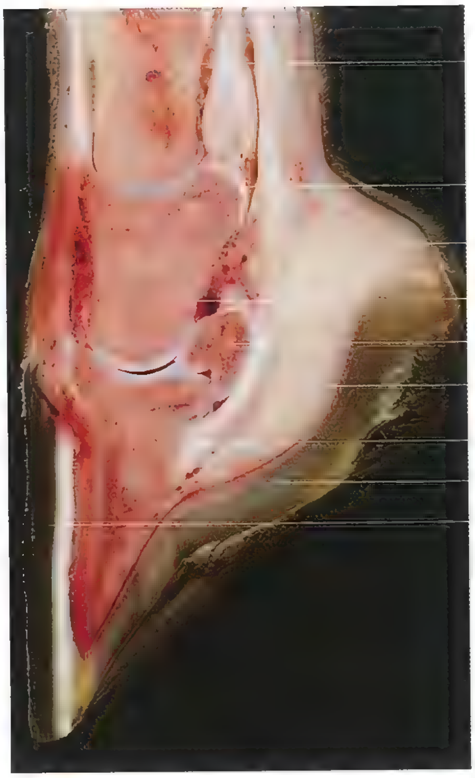


Fig. 18-59. Sagittal section of the foot of a horse (courtesy of PD Dr. S. Reese, Munich).

The major part of the ground surface is formed by the soft, elastic horn of the proximal part of the bulb, which dominates over the harder horn of the distal bulb and the sole segment.

The **dewclaws** of the small ruminants do not have skeletal components and are connected to the main digits by soft tissue only.

Blood supply and innervation

Blood supply and innervation of the hooves of small ruminants is similar to that of the bovine hoof with some minor species-specific variations with regards to the exact course and branches of the vessels and nerves.

Hoof (ungula) of the pig

The **anatomy of the hooves** of the pig is similar to that of ruminants (Fig. 18-57). However, the phylogenetic reduction of the digits is not quite as advanced in the pig than in ruminants. The accessory digits are caudal to the principal ones and have a full complement of bones, unlike the rudimentary dewclaws of ruminants.

The **skeleton of the dewclaws** is joined to the principal hooves by formation of a real joint. The lateral dewclaw is usually longer than the medial one and the dewclaws in the hind-limb are located more proximally than those of the fore-limb. Due to their reduction in length, the dewclaws do not have contact to the ground while standing on a hard surface, but bear weight on soft ground.

The **hooves** are straight and have a bulb that is set apart from the wall and sole. The bulb protrudes distally, so that the soft horn of its palmar/plantar part takes over the palmar/plantar half of the ground surface. The dorsal half of the ground surface is formed by the distal part of the bulb segment and the sole segment. The junction between the soft horn of the palmar/plantar part and the hard horn of the dorsal part of the bulb is predisposed for fissures within the horn. This problem usually occurs in animals kept on concrete and can lead to severe hoof problems.

Blood supply and innervation

Blood supply and innervation of the hooves of the pig is similar to that of the bovine hoof with some minor species specific variations with regards to the exact course and branches of the vessels and nerves.

Equine hoof (ungula)

K.-D. Budras and H. E. König

The **digital skeleton** of the horse is reduced to one ray, the **third digit,** which carries the hoof. Some individuals may be born with an additional second or fourth digit **(polydactylism),** which is usually shorter then the principal digit and does not contact the ground. Reduction of the skeleton to one weight bearing structure puts the third digit under considerable mechanical force. The integrity and condition of the hoof is essential to the horse.

Definition

The **term "hoof"** is sometimes used for the horny enclosure of the distal phalanx only, while in other contexts it includes the horny appendage as well as the enclosed musculoskeletal structures (Fig. 18-59):

- the distal part of the middle phalanx (os coronale),
- the distal interphalangeal joint (articulatio interphalangea distalis),
- the distal phalanx (os ungulare),
- the lateral and medial hoof cartilage (cartilago ungularis medialis et lateralis),
- the distal sesamoid (navicular) bone (os sesamoideum distale) with the terminal portion of the deep digital flexor tendon,
- the navicular bursa (bursa podotrochlearis) between the navicular bone and the deep digital flexor tendon.

Shape of the hoof

In the **new-born foal** the hooves are **bilaterally symmetrical** and have the same shape in all four feet. The typical differences in hoof form present in the **adult horse,** are the result of the forces exerted on the hoof during locomotion. This process starts immediately after birth and after a few month it is possible to distinguish left from right and front from hind feet in the isolated specimen. Confinement of young horses usually results in the development of hoof deformities.

The **angle the toe** makes with the ground is about 45–50° in the forelimb and slightly more (about 50–55°) in the hind. Correspondingly the ratio between the length of the wall to the height of the heels is about 3:1 in the front and 2:1 in the back. The **quarters** (lateral and medial walls of the hoof) descend toward the ground more steeply on the **medial side,** which can be used to identify left and right hoof specimens. The shape of the ground surface differs between front and hind feet: the **sole of front hooves** are more **circular,** while the ground surface of the **hind hooves** resemble an **egg** with the apex at the toe (Fig. 18-63).

Wall (paries corneus, lamina)

The wall can be divided into **several parts** (Fig. 18-58 and 64):

- the dorsal part or toe (pars dorsalis),
- the sides or quarters (pars lateralis et medialis),
- the heels (pars mobilis lateralis et medialis) and
- the bars (pars inflexa lateralis et medialis).

The toe is the most dorsal point of the hoof and its limit is described by two imaginary lines drawn from the apex of the frog in a 45° angle to the sole margin (Fig. 18-64). The quarters are the part of wall following the toe palmarly/plantarly to the widest part of the hoof. The rounded back of the hoof is termed the heels, which reflect upon themselves to continue forward for a short distance at the side of the frog as the bars. The bars provide stabilisation to the relatively thin and mobile horn of the heels.

Ground surface (facies solearis)

The **ground surface** of the hoof consists of (Fig. 18-63):

- the solar margin (margo solearis),
- the sole (solea cornea),
- the frog (cuneus corneus) and
- the bulbs of the heels (torus corneus).

The **sole** fills the space between the wall and the frog and forms most of the undersurface of the hoof. However, it is slightly concave so only the sole margin and the frog make contact on firm ground. Most of the body's weight is therefore carried by the sole margin. The sole consists of a **body** apically (corpus soleae) and **lateral** and **medial crura** (crus soleae lateralis et medialis) extending from the body palmarly/planetary to the **angle of the sole** (angulus parietis palmaris/plantaris lat. et med.) between the bars and quarters.

The **wedge-shaped frog** (cuneus ungulae) projects from behind between the two crura of the sole, from which it is separated by the **two paracuneal grooves** (sulcus paracunealis lateralis et medialis). It consists of **two crura** (crus cunei lateralis et medialis), that meet in the **apex of the frog** (apex cunei), that points towards the toe. The **base of the frog** (basis cunei) completes the space between the heels where it forms the palmar/plantar part of the hoof. The sole surface of the frog is marked by a **central groove** (sulcus cunealis centralis) to which an **internal spine** (spina cunei), the frog-stay, corresponds (Fig. 18-60).

Depending on the ground and the way the horse is shod, the frog contributes to the weight bearing surface of the hoof. The base of the frog is continuous proximally with the **bulbs of the heels** (torus corneus). Corresponding to the anatomy of the frog, the bulbs of the heel can be divided into **lateral** and **medial parts** (pars lateralis et medialis tori), separated by a **groove** (fossa intratorica), the continuation of the central groove of the frog.

Segments of the hoof

After isolation of the hoof capsule the **three proximal hoof segments** can be easily distinguished on the inside of the horn capsule and on the surface of the dermis (Fig. 18-61):

- Perioplic segment (limbus),
- Coronary segment (corona),
- Wall segment (paries).

The **limbic groove** (sulcus limbi) is located near to the coronary segment, between the perioplic and the coronary segment. The **ground surface** can be divided into the following segments (Fig. 18-62):

- Sole segment (solea) with its concave undersurface,
- Footpad (torus digitalis), which is divided into a distal part, the frog (cuneus ungulae) and a proximal part, the heel bulbs (torus ungulae).

Fig. 18-60. Transverse section of the hoof of a horse at the level of the angles of the sole (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-61. Dermis of the hoof after removal of the hoof shoe, lateral aspect (courtesy of PD Dr. S. Reese, Munich).

Fig. 18-62. Dermis of the hoof after removal of the hoof shoe, ground surface (courtesy of PD Dr. S. Reese, Munich).

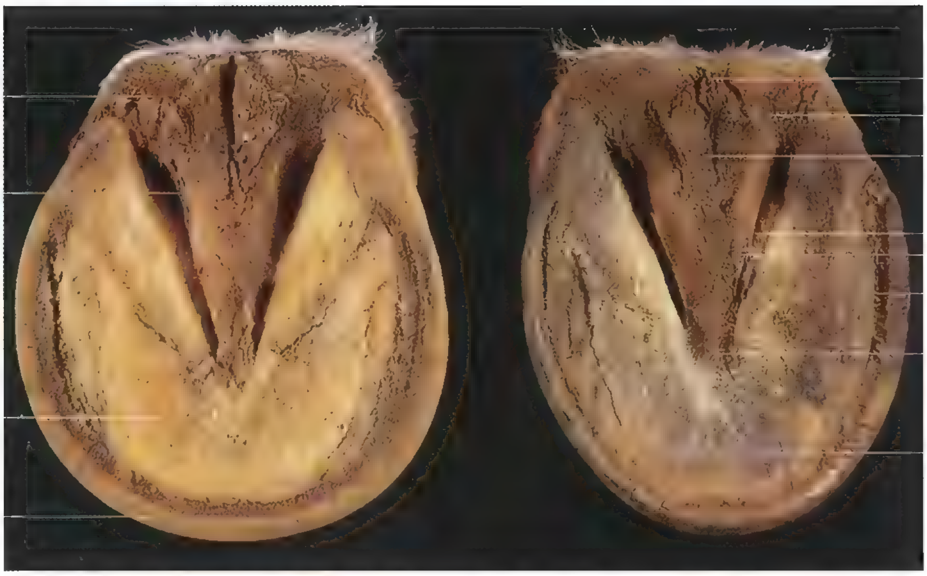


Fig. 18-63. Round ground surface of a front foot (left) and oval gound surface of a hind foot (right) (courtesy of Dr. S. Reese, Munich).

Perioplic segment (limbus)

The perioplic segment forms a band, a few millimetres thick, just distal to the hairy skin and extends onto the heel bulbs palmarly/plantarly.

The **subcutis of the periople** (tela subcutanea limbi) is modified to form the bulging perioplic cushion, which joins the heel bulbs on the back.

The **dermis of the perioplic segment** (dermis limbi) is studded with slender, few millimetre long papillae (papillae dermales) (Fig. 18-65).

The **epidermis of the perioplic segment** contributes the external layer (stratum externum) of the wall. It forms a band of soft rubbery horn a few millimetre thick near the coronet, but dries to a glossy thin layer distally (Fig. 18-66). The periople consists of an admixture of tubular and intertubular horn, which loses its tubular structure more distally. The perioplic horn is usually worn off, when it reaches the middle of the hoof wall.

The **horn cells** and the **membrane binding material** are able to bind water, so that the perioplic horn acts as a fluid reservoir to keep the underlying coronary horn moist and thus elastic. The lipid component of the membrane binding material prevents the horn from soaking up as well as from losing too much water.

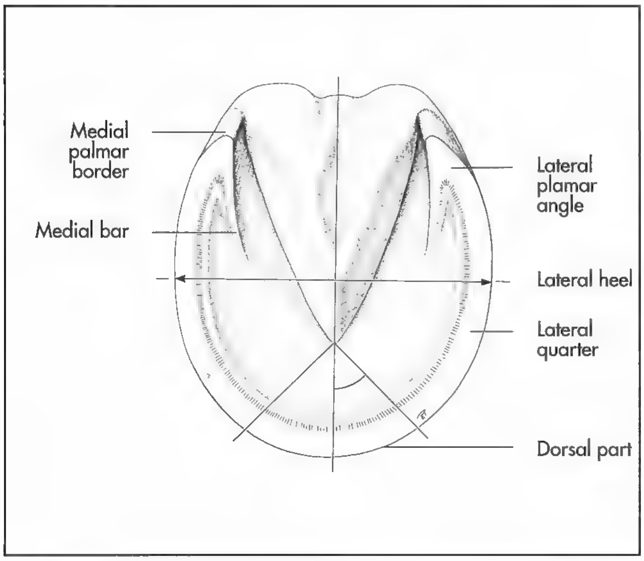


Fig. 18-64. Division of the hoof wall (paries corneus), schematic.

Coronary segment (corona)

The coronary segment constitutes a up to 15mm broad band distal to the perioplic segment (Fig. 18-65). The underlying **subcutis** (tela subcutanea coronae) is thickened to form the **coronary cushion** (pulvinus coronae), that bulges outward at the coronet.

The **coronary dermis** (dermis coronae) forms numerous papillae, that are up to 8mm long, arranged in rows and directed distally.

The **coronary epidermis** (epidermis coronae) produces horn of a distinct **tubular structure** (Fig. 18-66). It reaches a thickness of 1.2 cm and runs distally toward the weightbearing margin parallel to the parietal surface of the distal phalanx. It is very resistant to stress and strain and forms the **middle layer** (stratum medium) of the hoof wall. The coronary horn can be further subdivided into an **outer, middle** and **inner layer,** which are characterised by different types of horn tubules (Fig. 18-65). The outer layer is predominantly composed of horn tubules with an oval diameter. In the outer and middle layer the horn cells forming the tubules are arranged in several layers, resembling the architecture of an onion. This form of construction provides a maximum of re-

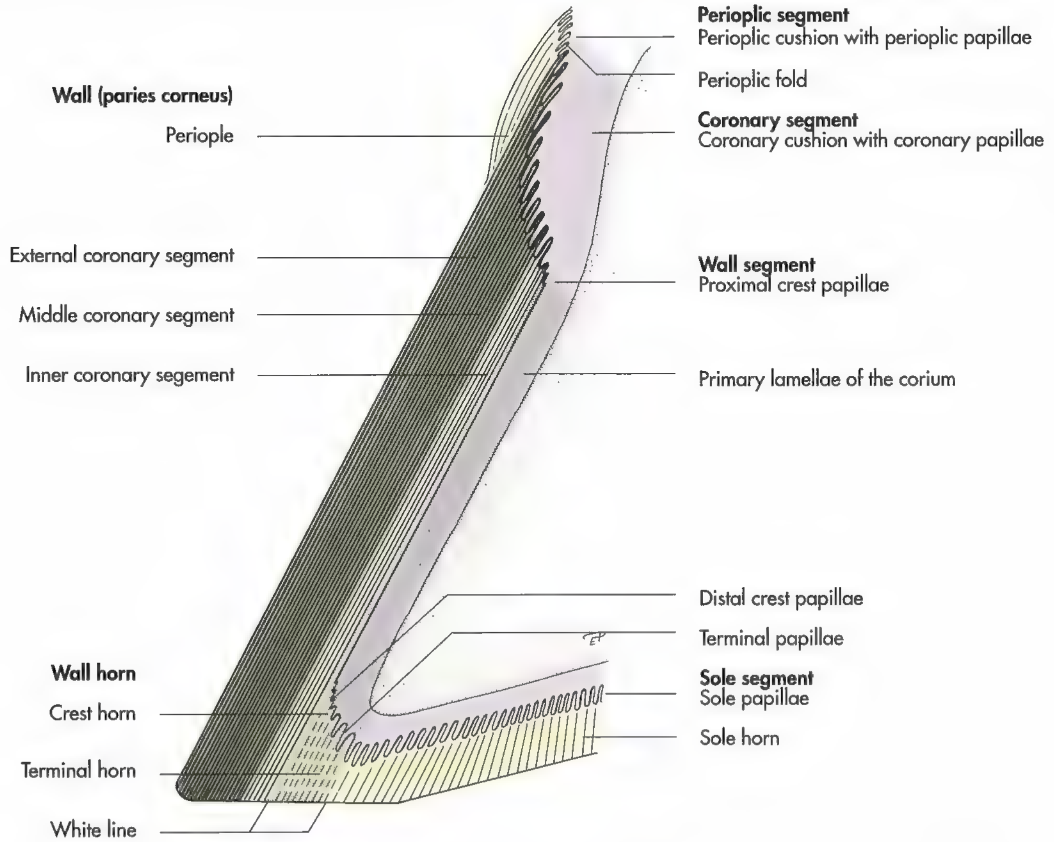


Fig. 18-65. Perioplic, coronary, wall and solar segment of the hoof wall of the horse, schematic.

sistance against radiate forces directed from the outside to the inside. The **inner layer** of the coronary horn consists of round horn tubules, which contain spindle-shaped horn-cells in its cortex. This arrangement provides resistance against forces, that are directed proximodistally, thus acting as shock-absorbers. The boundary between the inner and middle layer, where the two different horn types come together, is predisposed for fissures, which can lead to cracks in the hoof wall.

Wall segment (paries)

The wall segment forms the **internal segment** (segmentum internum), which lies beneath the coronary horn (Fig. 18-65). It becomes visible only on the surface of the sole as the **white line** (zona alba), the junction between the sole and the wall.

There is **no subcutis** underlying the wall segment. The reticular layer of the wall dermis **(dermis parietis)** is directly adjacent to the parietal surface of the distal phalanx.

The dermis of the wall segment consists of about 600 **primary laminae** (lamellae dermales), that run in a proximodistal direction and are in average 3.5 mm high in the warm-blooded horse. The primary laminae bear about 110 secondary laminae each, which are also orientated proximodistally (Fig. 18-67). They also carry some papillae on the crest at their proximal origin and at their distal ending. The distal crest papillae are continuous with the finger-shaped terminal papillae, which form the end of each lamina (Fig. 18-65).

Corresponding to the structure of the dermis, the epidermis of the wall segment also forms primary and **secondary laminae** (lamellae epidermales), that interdigitate with the dermal laminae. Only the primary laminae possesses a horny layer. They slide gradually toward the ground, pushed by continuous proliferation and appear on the ground surface as the white line.

The epidermis over the crest papillae forms horn tubules, which usually have lost their tubular structure before they reach the ground surface (Fig. 18-67). The cornification process for the **laminar horn** follows the **hard type,** while cornification over the **papillae** is of the **soft type.** The terminal horn formed by the epidermis over the terminal papillae at the distal end of the laminae consists of horn tubules with a wider diameter and large medullary spaces. In the white line, it becomes visible as yellow-brown horn, filling the gaps between the laminar horn.

The horn of the wall constitutes the junction between the coronary horn and the wall segment, which is firmly attached to the underlying bone. The long horn cells of the epidermal laminae are characterised by multiple fluid-filled chambers, that provide the elasticity of a multichambered waterbed.

The **white line** (zona alba) forms a flexible junction between the hard coronary and the softer sole horn (Fig. 18-68).

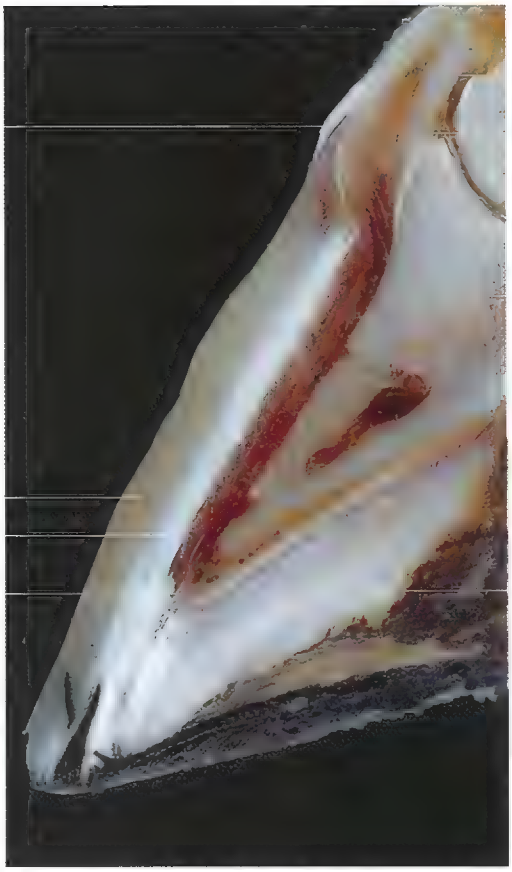


Fig. 18-66. Paramedian section of the dorsal part of the hoof of a horse, shwoing horn tubules.

Its width corresponds to the length of the epidermal laminae. The heterogeneous composition of the white line, where hard laminar horn is mixed with soft tubular horn causes the white line to be a **point of weakness** with regards to mechanical, chemical and biological damage. The **medulla of the horn tubules** undergoes early destruction and allows fluids and thus infectious agents to become established, resulting in an ascending infection.

The horn of the hoof in its function as barrier against environmental influences is more effective in the non-domesticated Przewalsky horse, than in the modern breeds of horses.

Sole segment (solea)

The sole segment fills the space between the wall and the frog and forms most of the **undersurface of the hoof.** It is slightly concave, so that only the sole margin and the frog have contact to firm ground. There is **no subcutis** underlying the sole segment. The dermis of the **sole segment** (dermis soleae) is in direct contact with the sole surface of the coffin bone. Its surface is studded with long papillae, which have a slightly apical orientation (Fig. 18-65).

The **sole epidermis** (epidermis soleae) has a tubular structure (Fig. 18-66). The horny layer, the sole horn, is on average 1 cm thick with considerable regional and individual variations. It has its greatest thickness towards the white line, thus providing some support to the latter. The **deeper layers** of the sole horn consist of a combination of tubules and intertubular horn, which form a firm unit similar to the coronary horn, although softer. The **superficial layers** are of a crumbly consistency, of a white-greyish colour and flake easily, which maintains the natural concavity of the sole.

Food pad (torus digitalis)

Like in ruminants the footpad of the horse can be divided into a distal (apical) and a proximal part. The apical part constitutes the frog (cuneus ungulae), the distal part the heel bulbs (torus ungulae). The bulbs are continuous proximally with the hairy skin and the perioplic segment (fig. 18-62 and 63).

Frog (cuneus ungulae)

The frog is the most important shock absorbing structure of the hoof (Fig. 18-60). Its W-shaped cross-section and its elastic horn allows the frog to yield the pressure forces when contacting the ground and so dissipates much of the resulting impact. When the foot loses contact to the ground, the pressure is released and the frog regains its original form. The **digital**

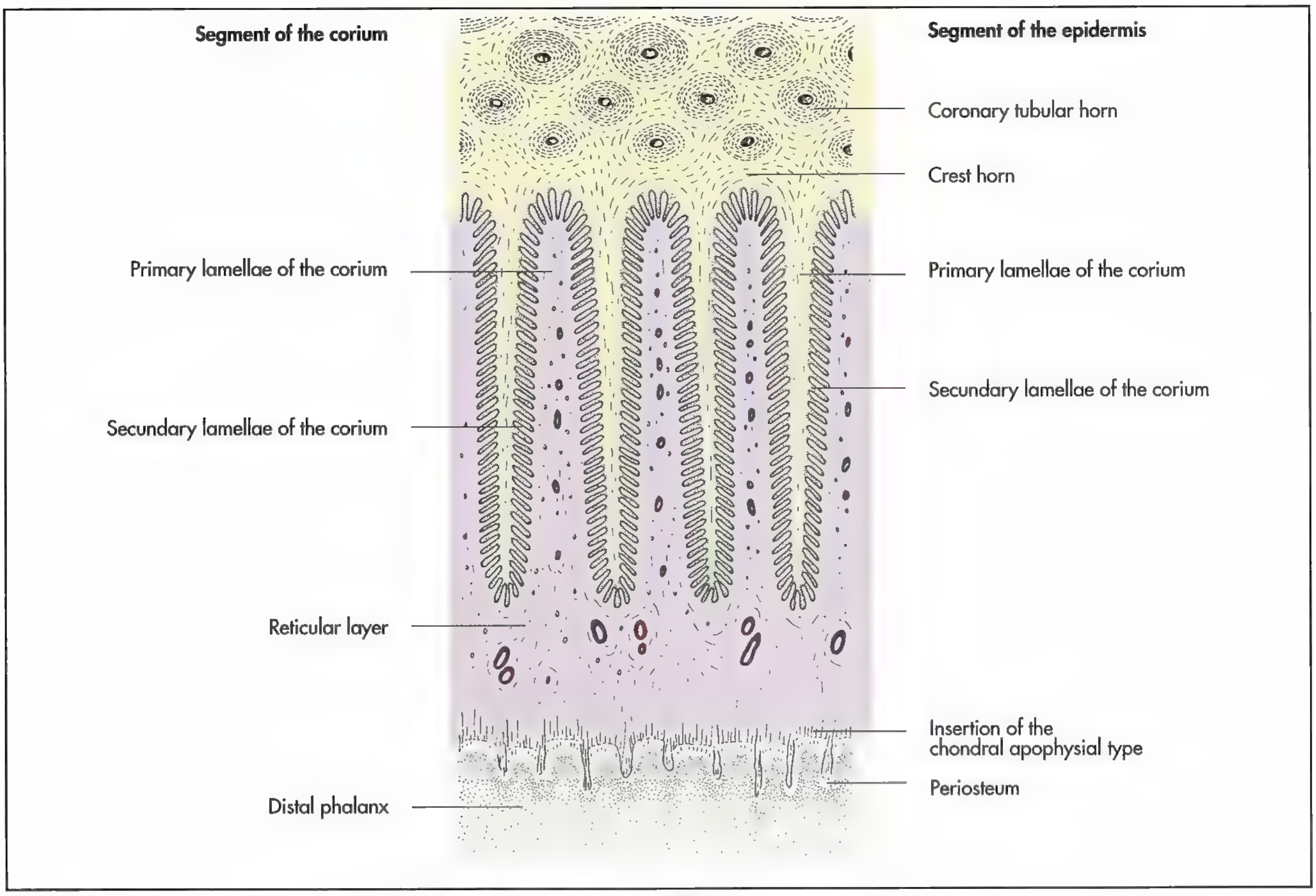


Fig. 18-67. Suspension of the distal phalanx, horizontal section, schematic.

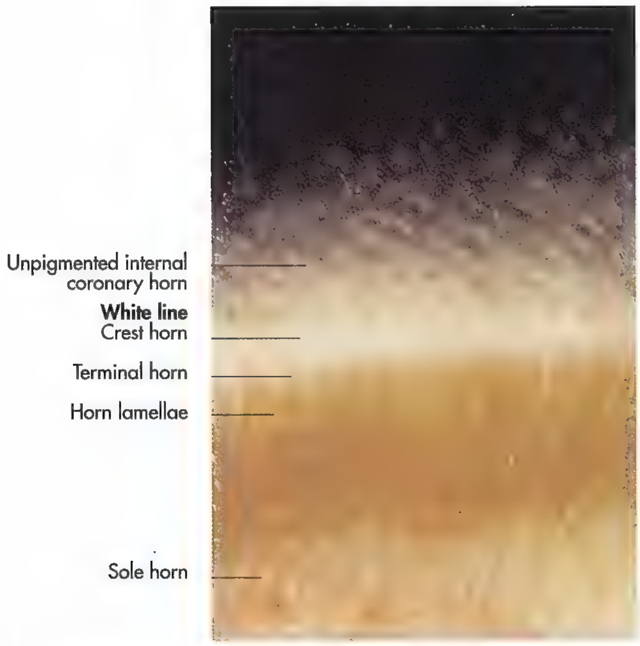


Fig. 18-68. White line (zona alba) of an equine hoof (courtesy of PD Dr. S. Reese, Munich).

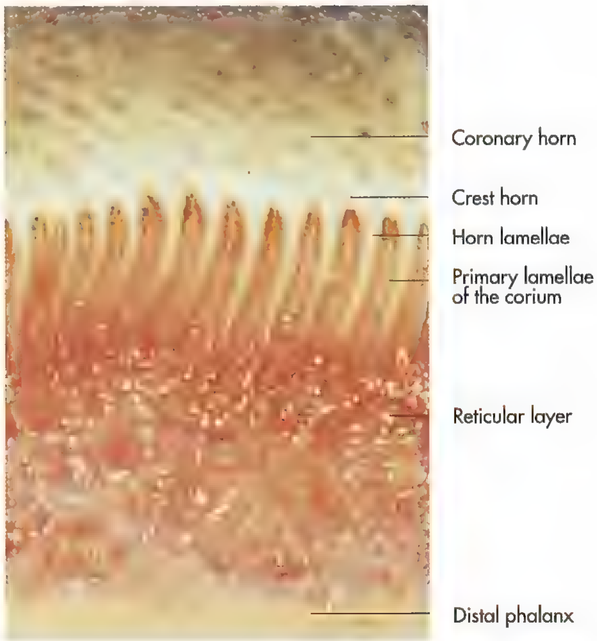


Fig. 18-69. Suspension of the distal phalanx of an equine hoof, horizontal section (courtesy of PD Dr. S. Reese, Munich).

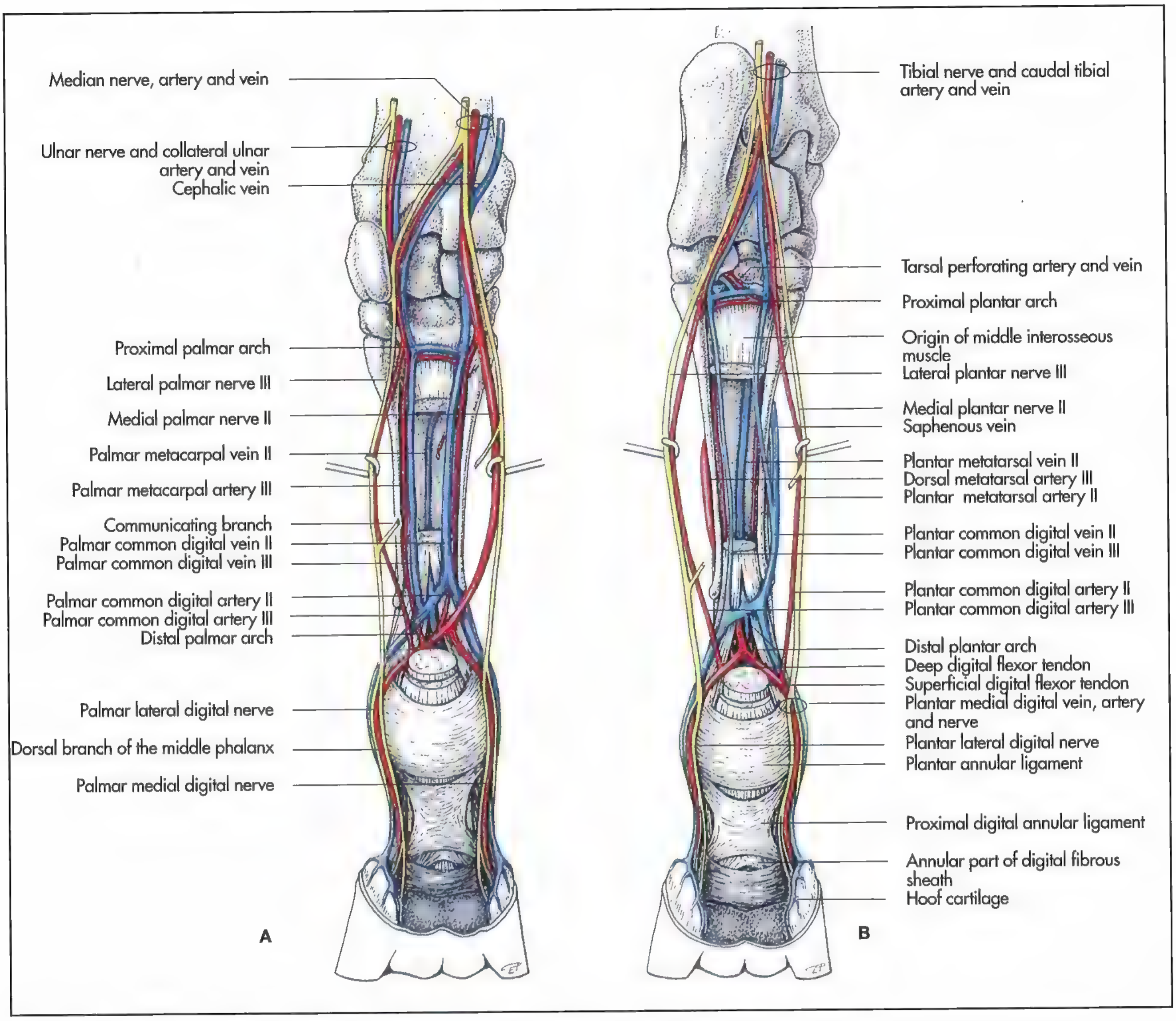


Fig. 18-70. Blood vessels and nerves of the autopodium of the fore- and hindlimb of the horse (**A** palmar aspect, **B** plantar aspect).

cushion deep to the frog (pars cunealis pulvini digitalis) complements this shock absorbing function (Fig. 18-60).

The **dermis of the frog** (dermis cunei) is densely covered with plump papillae, which are shorter than those of the sole dermis and have a spiral orientation. The **epidermis of the frog** (epidermis cunei) does not have a granular layer and the produced horn is fairly soft and elastic. The horn tubules spiral to the surface following the dermal matrix. The frog is a predisposed location for foreign bodies, e.g. nails, which may penetrate underlying vital structures, such as the navicular bursa. These injuries require immediate veterinary attention.

Heel bulbs (torus ungulae)

The **digital cushion** underlying the frog continues under the **heel bulbs** (pars torica pulvini digitalis). The dermis of the heel bulbs (dermis tori) is also continuous with the dermis of the frog (Fig. 18-62). Its surface carries slender papillae that are similar to those of the perioplic segment. The **epidermis of the bulbs** (epidermis tori) includes a granular layer and cornification follows the **soft type.** The horn layer is relatively thin and consists predominantly of intertubular horn. Within the epidermis of the heel bulbs and at the base of the frog are modified sweat glands (glandulae tori).

Suspension of the distal phalanx

The distal phalanx is suspended within the horn capsule by the **dermis** and **epidermis** of the **proximal segments** that form the hoof wall and are firmly united with the **periosteum** of the bone (Fig. 18-67).

This **anatomical arrangement** protects the distal phalanx against overload. Compressive stress on the bone is transformed into tensile forces by the suspension of the distal phalanx on the

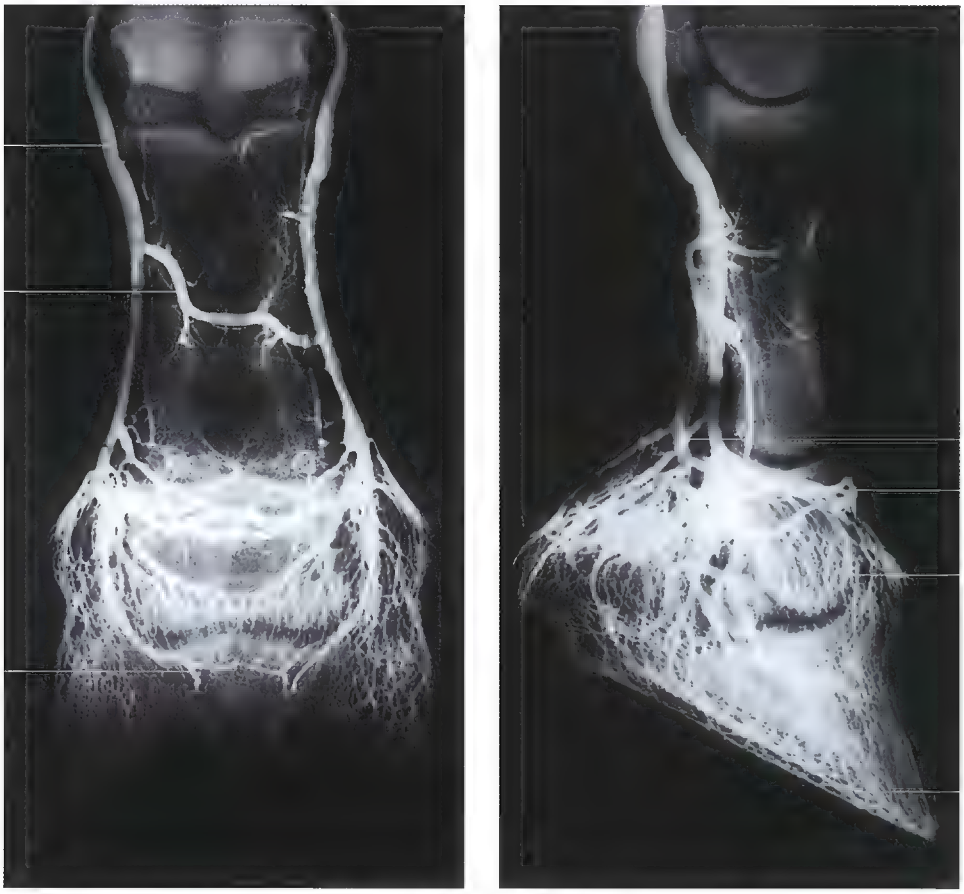


Fig. 18-71. Arteriogram of the foot of a horse, dorsopalmar (left) and lateromedial (right) projection (courtesy of PD Dr. S. Reese, Munich).

hoof wall and then transformed into compressive stress on the sole margin. The dermis is bonded to the parietal surface of the distal phalanx by linear, proximo-distally directed insertion zones, that consists of non-mineralised fibrous cartilage at the surface overlying mineralised fibrous cartilage. Apart from providing attachment to the dermis, these insertion zones also constitute the cartilagenous growth plates that are responsible for the growth of the distal phalanx. Periosteum fills the spaces between those cartilagenous zones and is the site of desmal osteogenesis.

The **collagenous fibres** of the dermis extend through the **reticular layer** (stratum reticulare) to form the **primary dermal laminae,** which carry **secondary laminae,** that interdigitate with the epidermal laminae. The tensile force is transmitted onto the secondary epidermal laminae, that consists of epidermal, vital matrix cells and then onto the primary epidermal laminae, which are joined to the coronary horn tubules. Starting at the distal phalanx, the oblique proximo-distal orientation of the collagenous fibres is continuous throughout the primary and secondary laminae. The horn cells and the keratin filaments are orientated in the same direction. The **development of secondary laminae** provides a larger surface area, thus a firmer junction, which can withstand the considerable forces that the hoof of the horse is subjected to.

In **horses with laminitis,** the suspension of the coffin bone is destroyed and the bone starts to sink or rotate. If all segments are affected as in very severe cases, the hoof shoe completely separates from the dermis.

Hoof biomechanics

The forces, acting on the distal phalanx, are transmitted to the wall of the hoof and trigger the hoof mechanism. The proximal part of the wall is retracted inward, while the heels are spread. The sole flattens and the frog broadens. When the foot is off the ground, the hoof regains its original form, which possible due to the elastic nature of the hoof horn.

Evidence of this to-and-fro movement of the heels, is found in the polished proximal surface of horse-shoes in this area. It is vital that horse shoes are not nailed to the wall in this region, otherwise this mechanism would be impeded. Thus, the shoe is nailed to the wall at the toe and the quarters only.

Horn production

The **rate of horn production** varies in the **different segments.** It also differs considerably between individuals and is generally most rapid in horses under five years of age. Coro-

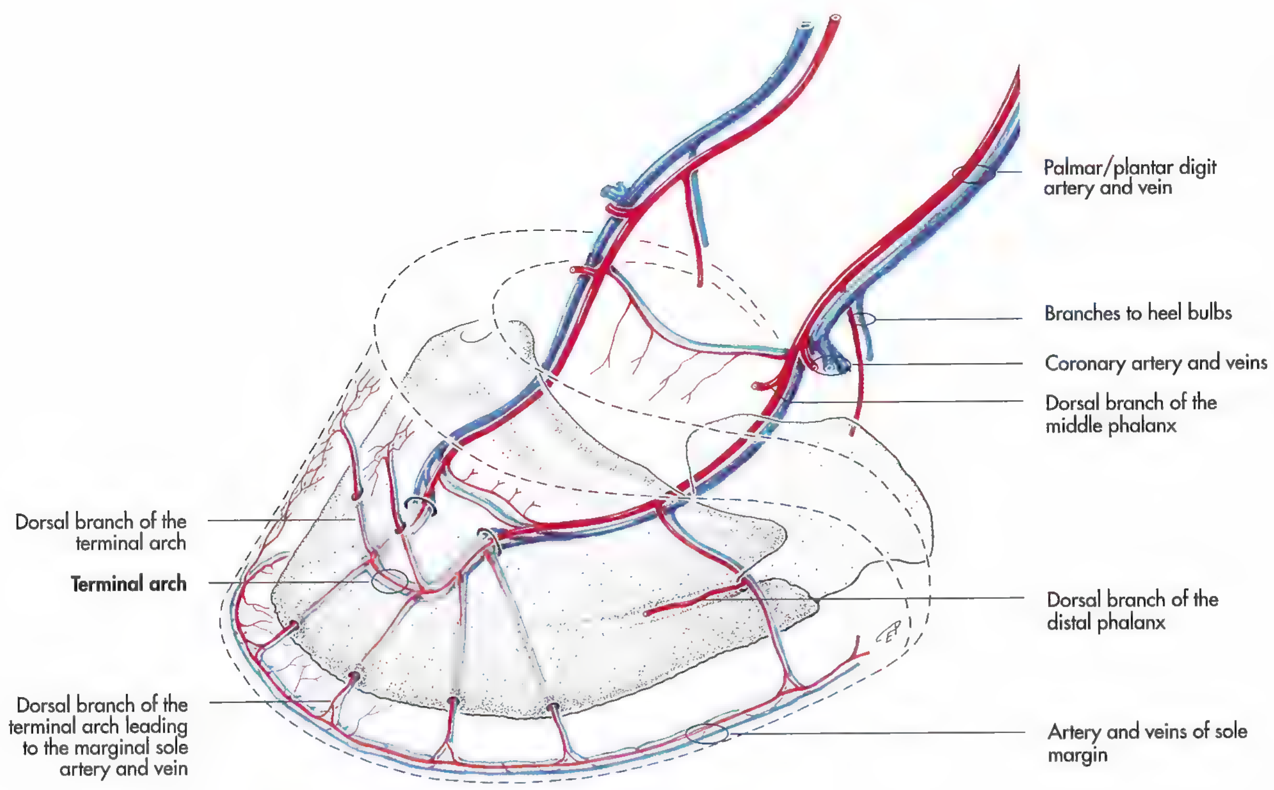


Fig. 18-72. Blood vessels of the distal phanlanx of the horse, schematic.

nary horn is produced at a rate of about 8–10 cm per year. Thus, it is renewed completely every year and any improvements in horn quality achieved by dietary supplementation will take a full year to become apparent.

Sole and **frog horn** grows about 6mm a year. Non-domesticated Prezwalsky horses show a seasonal cycle with higher growth rates in summer and slower growth in winter.

Blood supply

Arteries

Blood supply to the hoof is provided by two arteries, the **lateral and medial palmar/plantar digital artery** (a. digitalis palmaris/plantaris lateralis et medialis), that are branches of the palmar common digital artery and the **dorsal metatarsal artery III** (a. digitalis palmaris communis/a. metatarsea dorsalis III) respectively. In the pelvic limb, the **small plantar common digital arteries II** and **III** also contribute to the formation of the digital arteries. Branches to the **heel bulbs** (rami tori digitalis) and medial and lateral coronary arteries are given off at the level of the middle phalanx (Fig. 18-70).

After sending branches to the frog and the different parts of the hoof wall, they enter the distal phalanx from medial and lateral and anastomose within the bone to form a **terminal arch** (arcus terminalis). From the terminal arch extend 8-10 vessels distally, that leave the bone at the sole margin to form the artery of the sole margin (a. marginis solearis) (Fig. 18-72).

Veins

The dermis of the hoof includes a dense venous network, that forms the **vein of the sole margin** (v. marinas solearis) distally and is connected to the **venous terminal arch.** An additional venous network is found on the inside of the hoof cartilages. Large veins pass through the hoof cartilage and connect the venous plexus of the sole and parietal dermis. Venous drainage is achieved by numerous coronary veins, branches of the **veins of the digital cushion** (v. tori digitalis) and the vein of the sole margin. These ultimately drain into the **lateral** and **medial palmar/plantar digital vein** or in the **terminal arch,** formed by these veins within the distal phalanx.

Lymphatic drainage

Lymph from the hoof of the thoracic limb drains to the **cubital lymph nodes** (lymphonodi cubitales), that of the pelvic

Fig. 18-73. Horn of an eight year old cow with distinct horn rings.

limb to the **deep popliteal lymph node** (lymphonodi poplitei).

Innervation

Thoracic limb

Unlike in other species, sensory innervation of the front hoof in the horse is provided exclusively by branches of the **median nerve.** The **common palmar digital nerves II** and **III** continue as **lateral** and **medial palmar digital nerves** after detaching a dorsal branch to the perioplic, coronary and wall segment. The palmar digital nerves send **branches** (rami tori) to the heel bulbs, coffin joint and the navicular complex and innervate the palmar part of the hoof cartilages, the wall, sole, frog and heel bulbs.

Pelvic limb

The **common digital nerves II** and **III** are branches of the **tibial nerve.**

Their branching pattern is similar to that of the corresponding nerves of the thoracic limb. The toe of the hoof receives additional innervation by the lateral and medial dorsal metatarsal nerves, branches of the deep fibular nerve.

All these nerves are blocked at various levels in the diagnosis of lameness. The principle behind this procedure is that a lame horse will go temporarily sound when the painful area is desensitised. A sequence of injections, in which increasingly larger territories are desensitised is therefore required to locate the site of the lesion.

Horn (cornu)

Chr. Mülling

The horn of the domestic ruminants consists of a bony core, enclosed in a modification of the common integument, the horn sheath. The skeletal component of the horn is provided by the **cornual process** (processus cornualis), that is firmly joined to the frontal bone. A hairless and glandless modification of the common integument covers the ridged and porous surface of the cornual process. The epidermis of the horn is heavily cornified and forms the horn sheath, which can be described as the horn in its narrowest sense.

The horn can be divided into:

- Base (basis cornus),
- Body (corpus cornus),
- Apex (apex cornus).

In wild ruminants, the **horns** (cornua) are used as weapons during breeding season or with regards to the pecking order. This explains their extremely stable anatomy. Unless the animal belongs to a naturally polled breed, in the domestic ruminants horns are found in both sexes, although those of males are usually more massive.

Unlike antlers, a characteristic anatomic feature of the male in the deer family, which are shed and replaced yearly under hormonal influence, the horns of the domestic ruminants are permanent and grow continuously following their first appearance after birth. Size and shape is strongly characteristic for the breed and depends upon age and gender.

Fig. 18-74. Longitudinal section of the horn of a 1.5 year old bull with beginning pneumatisation of the cornual process (courtesy of PD Dr. S. Reese, Munich).

Bovine horn (cornu)

Development of the horn

As early as in the third month of gestation, there is a small epidermal hillock visible, where the horn will later grow. In the new-born animal a hair whorl indicates the location of the later horn and the small hillocks are hairless on top. Beginning at the centre the whole horn becomes gradually hairless.

Cornual process (processus cornualis)

The cornual process of the ox develops as exophysis of the frontal bone. Its formation from the frontal bone is induced by the epidermal hillock. The development of the bony component of the horn begins relatively late in gestation. Only shortly before parturition a small bony enlargement is detectable beneath the epidermal hillock. This enlargement keeps growing up to five months post partum to form the solid cornual process. Development of the horns is often prevented by cauterisation of the germinal epidermis at an early age.

Pneumatisation of the cornual process

From the sixth month post partum onwards the cornual process starts to pneumatise by invasion of the mucosal lining of the frontal sinus into the cornual process (Fig. 18-74). This process continues until the whole bone is hollow, with the exception of the solid apex. Due to the wide communication, the frontal sinus is exposed when an adult animal is dehorned or the horn fractures. Protection against dirt and prophylaxis against infection is therefore strongly recommended in these cases.

Horn sheath

Cornual subcutis (tela subcutanea)

There is no subcutis present in the horn. The dermis is directly adherent to the bone, thus providing a very stable junction between the horny enclosure and the cornual process.

Cornual dermis (dermis cornus)

The dermis carries distinct papillae (papillae dermales seu coriales). In the base and body of the horn the papillae are arranged parallel to the dermal surface, while in the apex they are more erect. The papillae of the body are very long (5–6 mm) and are arranged in groups in such a way, that they appear to form laminae.

Cornual epidermis (epidermis cornus)

Vital epidermal cells cover the whole dermal surface. Using the dermal papillae as the matrix, the epidermis forms **tubular horn** (tubuli epidermales). Growth of the horn takes place predominantly at the base of the horn and the new horn pushes old layers apically. Horn growth follows the direction of the dermal papillae. Thus the horn gains predominantly in length and only very little in diameter.

The rate of horn growth is largely dependent on the nutrition that the epidermal cells receive. When nutrition is impaired (seasonal in wild ruminants), during pregnancy or lactation, horn production slows down. It is usual to find the horns marked by alternating rings of greater or lesser thickness. The latter represent periods when production was less active. In cows these rings usually correspond to pregnan-

Fig. 18-75. Skull of a goat with straight horns (courtesy of PD Dr. S. Reese, Munich).

cies. Since the first calf is generally born when the cow is about two years of age and subsequent calves are born at yearly intervals the age of the cow equals the number of horn rings plus two (Fig. 18-73).

The softer outer layer of the horn sheath (epiceras) is produced by an epidermals strip at the base of the horn, that is transitional to the ordinary epidermis and corresponds to the periople of the hoof.

Blood supply

Blood supply of the horn is provided by the **cornual arteries** and **veins** (aa./vv. cornuales), that are terminal branches of the **superficial temporal artery** and **vein** (a./v. temporalis superficialis).

The **cornual artery** runs parallel to the temporal line to reach the base of the horn, where it ramifies into a smaller dorsal branch and a larger ventral branch. The dorsal branch passes over the dorsal aspect of the base of the horn and supplies the dermis and the cornual process. The ventral branch runs on the ventral aspect of the horn base, where it detaches branches to the dermis and the bone. It curves medially to anastomose with the corresponding artery of the contralateral horn.

The smaller branches of these arteries run in grooves and canals of the cornual process and retract when severed, so it is impossible to grasp them with haemostats to prevent excessive bleeding. Because of this anatomical arrangement it is essential to perform an amputation of the horn as close as possible to the frontal bone, before the vessels enter the bone. The dermis of the horn is exceptional well vascularised. Horn injuries or separation of the horn sheath from the bone are usually accompanied by severe and extensive bleeding. Most of these cases require amputation of the horn at the horn base, where haemostasis can be achieved before the supplying vessels enter the bone.

Lymphatic drainage

Lymph from the horn drains to the **parotid lymph node** (lymphnodus parotideus).

Innervation

The horn is supplied mainly by the **cornual branch** (rami cornualis) of the **zygomaticotemporal nerve,** a division of the **trigeminal nerve.** Due to the close topography it is difficult to decide, whether it is a branch of the maxillary or the ophthalmic division of the trigeminal nerve. Additional innervation is provided by the supraorbital and the infratrochlear nerve, on its passage through the frontal sinus.

The cornual branch arises within the orbit and leaves the orbit caudal to the zygomatic process of the frontal bone. It passes caudally, protected by the prominent ridge of the temporal line to reach the base of the horn. Close to the orbit it is embedded in fat, while further caudal it is covered by skin and the frontal muscle only.

The **cornual branch** is commonly anaesthetised for dehorning. The injection site is found caudal to the midway between the temporal angle of the eye and the horn, just ventral to the temporal line. The anaesthetic technique is not always successful. Failure can be due to variations of the course of the cornual branch or the existence of unusual substantial contributions from the supraorbital or infratrochlear nerves.

Fig. 18-76. Skull of a sheep with helical horns (courtesy of PD Dr. S. Reese, Munich).

Horn (cornu) of the small ruminants

The horns of the small ruminants differ in form, but not in the basic anatomy from the horns of cattle. They arise close behind the orbits in a parietal position quite unlike the temporal position of cattle. The horns of sheep pursue a helical course (Fig. 18-76), while those of goats grow caudally over the skull (Fig. 18-75), the exact form and size depending on breed, sex and age.

Cornual process (processus cornualis)

Each cornual process originates from a separate **ossification centre** (os cornuale), which makes a secondary fusion to the frontal bone (os frontale). The cornual process of goats generally have an oval section, while those of sheep are triangular in section.

Horn sheath

Growth of the horn is intermittent and results in a very corrugated external surface of the horn. Several ridges (usually 8–14) are formed during each year.

Blood supply and innervation

The horns of sheep and the goat are located so close to the orbit that the supplying **superficial temporal artery** and **vein** and the cornual nerve ascend directly dorsal to the zygomatic process. In contrast to the ox, the supplying structures run on the surface of the frontoscutular muscle. The cornual nerve appears between the blood vessels and the zygomatic process close to the temporal canthus of the eye. Local anaesthesia of this nerve can be performed at the caudal origin of the zygomatic process about 1cm below the skin. The horn of the goat receives additional supply from branches of the infratrochlear nerve. These can be reached by a second injection at the dorsomedial margin of the orbit.

Clinical terms related to the common integument:
Dermatitis, pyodermitis, folliculitis, laminitis, mastitis, mastectomy.

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Glossary of Terms

A

Ab	away from
abaxialis	away from the axis
Abdomen	abdomen
abducens	leading away, drawing away
Abductor	abductor
absorbere	to absorb
accelerans	accelerating
accessorius	additional
Acetabulum	acetabulum
Acinus	acinus
Acromion	acromion, shoulder level
Acropodium	acropodium, fore and hind digits, outermost end of the limbs
acusticus	concerning hearing
acutus	sharp
Adhaesio	adhesion
Aditus	aperture, inlet
adnexus	added, connected with
adiposus	fatty
afferens	feeding
Ala	wing, or winglike
albugineus	whitish
Allantois	allantois
alveolaris	belonging to the alveolus
Alveolus	alveolus, small hollow
Alveus	belly, excavation
Amphiarthrosis	tight-flexible joint
Ampulla	ampulla, club-shaped receptacle
amygdaloideus	almond-like
Anastomosis	anastomosis, junction
analis	belonging to the anus
anconeus	belonging to the elbow
Angulus	angle
Ansa	loop
anserinus	anserine, goosefoot-shaped
Antebrachium	forearm
anterior	situated before or toward the front
Antrum	antrum, cavern
Anulus	anulus, small ring
Anus	anus, ring
Aorta	aorta
Apertura	aperture
Apex	apex, tip
Aponeurosis	aponeurosis, flat tendon
Apophysis	apophysis, outgrowth
Appendix	appendix
Aquaeductus	aqueduct, water pipe
Arachnoidea	arachnoid
Arbor	tree
arcuatus	curved
Arcus	arc, arch
Area	area
Arteria	artery
Arteriola	arteriole, small artery
Articulatio	articulation, joint
ascendens	ascending
asper	rough
Asthenia	weakness
Asthma	breathlessness
Atlas	atlas, carrier
Atresia	atresia, absence of a natural orifice
Atrium	atrium
Atrophia	atrophy
auricularis	ear-shaped, belonging to the ear
Auris	ear
autochthon	formed on the spot
autonomicus	independent
Avis	bird
Axilla	axilla
Axis	axis, second cervical vertebra
Axon	axon, axle
azygos	unpaired

B

Basis	base
Basipodium	basipodium, tarsus
biceps	two-headed
bifidus	divided into two (parts)
Bifurcatio	bifurcation
bilateralis	two-sided
biliaris	belonging to the bile
bilifer	bile-bearing
Bilis	bile
Blastema	blastema
Blastos	germ
brachalis	belonging to the arm
brevis	short

bronchialis	belonging to the bronchus
Bronchus	bronchus
Bucca	cheek
buccalis	belonging to the cheek
Bulbus	bulb
Bulla	bulla, bubble
Bursa	bursa, pouch

C

Calcaneus	calcaneus, calcaneum,heel bone, calcaneal bone
Calcar	spur
Calix	calyx, calix, calice, goblet
Callus	callosity
Calvaria	roof of skull
Camera	chamber
Canaliculus	canalicule, small duct
Canalis	canal, tube
caninus	belonging to the dog
Capillus	scalp hair
Capitulum	small head
Capsula	capsule, small cap
Caput	head
Cardia	cardia, part of stomach adjacent to cardiac opening
Caries	caries
carneus	fleshy
Carotis	carotid
Carpus	carpus
Cartilago	cartilage
Caruncula	caruncle
Cauda	tail
caudatus	tailed
cavernosus	abounding in caves
Cavitas	cavity, cave
Cavum	cavity
Cecum	c(a)ecum
cecus	blind
Cellula	cell
centralis	lying in the centre/-er
Centrum	centre, center
cephalicus	belonging to the brain
Cerebellum	cerebellum
Cerebrum	cerebrum, brain
Cerumen	ear wax
cervicalis	belonging to the neck
Cervix	neck
Chiasma	chiasm, crossing
Choana	choana, funnel
Chole	bile
choledochus	bile-bearing
Chondro	cartilage
Chondrosis	chondrification
Chorda	cord
choroidea	choroid
Chylus	chyle
Ciliaris	belonging to the eyelid
Cilium	eyelash
Cingulum	girdle
Circulus	circle
circum-	all around
Circumferentia	circumference
circumflexus	bent
Cisterna	water cave
Claustrum	claustrum, occlusion
Clavicula	clavicle
clinoideus	bed-like
Clitoris	clitoris
Clivus	declivity
Cloaca	cloaca, sewer
Clunis	hindquarter
coccygeus	belonging to the coccyx
Cochlea	cochlea
colicus	belonging to the transverse colon
Collapsus	collapse
collateralis	lying at the side
Colliculus	colliculus, a small elevation
Collum	neck
Colon	colon
Colpos	sheath
Columna	column
Commissura	commissure, connection
communis	common
compactus	compressed
complexus	combined
compositus	composed
Compressio	compression, pressing together
Concha	conch(a)
Condylus	condyle
congenitalis	congenital
Confluens	confluence
conjugatus	connected
conjunctivus	serving the connection
Conjunctiva	conjunctiva
Connexio	connection
Consecutio	consequence
contactus	touched
Conus	cone
convolutus	convoluted
Cor	heart
coracoideus	raven(bill)-like
Corium	corium
Cornea	cornea, horny skin
Cornu	horn
Corona	coronet, crown
coronoideus	like a crown
Corpus	body
Corpusculum	corpuscle, small body
Corrugator	wrinkler
Cortex	cortex, rind, bowl
corticalis	belonging to the cortex
Costa	rib
Coxa	hip bone
Cranium	cranium, skull
crassus	thick
Cremaster	loop, hanger, tab
cribrosus	sieve-like
Cribrum	sieve
cricoideus	ringlike

Crista	crest, comb
cruralis	belonging to the thigh
Crus	(lower) leg, thigh
Crypta	crypt, indentation
Cubitus	elbow
Culmen	culmen, highest pitch
cuneatus	cuneate
cuneiformis	cuneiform
Cunnus	pudenda
Cupula	dome
Curvatura	curvature, curve
curvus	bent
Cuspis	cusp, lancehead
cutaneus	belonging to the skin
Cuticula	cuticle
Cutis	skin
cyclicus	circular
cysticus	belonging to the gall (bladder)
Cystis	bladder
cyto-	cell

D

Dartos	skinned
Decidua	invalidated skin
Declive	declivity, slope
Decussatio	decussation, crossing, overlapping
Defaecatio	evacuation of one's bowels
deferens	leading down
delabens	rolling down
deltoideus	deltoid, triangular
Dendritum	dendrite, tree
Dens	tooth
Dentin	dentin(e)
Dermis	dermis, skin
descendens	descending
dexter	on the right
Diameter	diameter
Diaphragma	diaphragm, septum
Diaphysis	shaft of a bone
Diastema	diastema, interspace
Diastole	slackening of the muscle of the (heart) ventricle
Diarthrosis	joint
Diencephalon	diencephalon, interbrain
digestorius	serving the digestion
digitalis	belonging to the finger
Digitus	digit, finger
Diplöe	diploë, double layer
dis-	apart
Discus	disk, disc
disseminatus	distributed
Dorsum	back
Dromos	course, run
Ductus	duct, canal
Duodenum	duodenum, twelve times
durus	hart
dys-	faulty
Dysplasia	dysplasia, malformation
Dyspnoe	breathlessness

E

ecto-	outside
efferens	leading out
Ejaculatio	throwing out
embryonalis	belonging to the embryo
Eminentia	eminence, elevation
Emissarium	discharge
en-	within
Enamelum	enamel (of tooth)
Encephalon	encephalon, brain
endo-	inside
Enteron	entrails
epi-	up, upon
Epidermis	epiderm(is)
Epididymis	epididymis
Epiglottis	epiglottis
epiploicus	belonging to the omentum
Epiploon	(greater or major) omentum
Epistropheus	axis, second cervical vertebra
epithelialis	belonging to the epithelial tissue
equinus	coming from the horse
esophagus	esophagus
Ethmo	sieve
Excavatio	hollow, cavity
excretorius	secreting
exo-	outside
Exspiratio	exhalation
Extensor	extensor
externus	outside
Extremitas	extremity

F

Facialis	belonging to the face
Facies	face
falciformis	sickle-shaped
Falx	falx, sickle
Fascia	fascia, bandage
Fasciculus	(small) bundle
Fastigium	gable
femininus	female
femoralis	belonging to the thigh
Femur	thigh
Fenestra	window
Fetus	f(o)etus
Fibra	fibre
fibrosus	fibrous
Fibula	fibula, grip
fibularis	belonging to the fibula
filiformis	filiform
Filum	thread
Fimbria	fimbria, fringe
Fissura	fissure, cleft
Fistula	fistula, tube
flavus	yellow
Flexor	flexor
Flexura	flexure, bend
Flocculus	floccule, small flake
fluctans	flowing
Folium	leaf
Folliculus	follicle, small sac

Fonticulus	fontanelle, small spring, source
Foramen	foramen, small hole
Formatio	formation
Fornix	fornix, arch (of a vault)
Fossa	fossa, ditch
Fovea	fovea, pit
Foveola	foveola, fossula
Frenulum	frenulum, (small) ligament
Frons	forehead
frontalis	belonging to the forehead
fundiformis	catapult-shaped
Fundus	fundus, ground
fungiformis	fungiform
Funiculus	(small) cord
fusiformis	spindle-shaped

G

Galea	(leathern) galea, helmet
Gallus	fowls, cock
Ganglion	ganglion
Gaster	stomach
gemellus	double
Genesis	generation
genitalis	belonging to the genitals
Genu	knee, stifle
Gingiva	gum
Glabella	small bald head
Glandula	gland, small glans
Glans	glans
Glia	glue
Globus	globe, sphere
Glomerulum	glomerulus, small glomus
Glomus	glomus
Glossa	tongue
Glutaeus	gluteal muscle
glyco-	sweetish
gracilis	gracile
Granulatio	granulation
granulosus	granular
Graviditas	pregnancy
griseus	grey
gustatorius	serving the taste
Gyrus	convolution

H

Habenula	habenula, rein
Haematoma	h(a)ematoma
Hallux	big toe
hamatus	hooked
Hamulus	hamulus, hooklet
Helix	helix, spiral
hem-	blood
Hemisphaerium	(cerebral) hemisphere
Hepar	liver
Hernia	hernia
heteros-	heterogeneous, strange
Hiatus	hiatus, gaping hole
Hilus	stalk, hilus, small incision
Hippocampus	hippocampus, seahorse
homos-	homogenous, equal
horizontalis	horizontal
hyalos-	transparent
hydro-	water
Hymen	hymen
Hyoid	lower part of the hyoid
hyper-	over
hypo-	under
hypogastricus	lying under the stomach
hypoglossus	lying under the tongue
Hystera	uterus

I

Ikterus	jaundice
Ileum	ileum
Ileus	ileus
iliacus	belonging to the ileum
impar	dissimiliar
Impressio	impression
Incisura	notch
Incontinentia	incontinence, inability
Incus	anvil
infra-	below
infraspinatus	lying below the spine of the shoulder blade
Infundibulum	infundibulum, funnel
inguen	groin
inguinalis	belonging to the inguen
Inspiratio	inhalation
Insufficientia	insufficiency, inability
Insula	island
insultus	injured
Integumentum	integument
inter-	between
intermedius	lying in the middle between others
internus	inner
Intersectio	intersection, incision
Interstitium	interstitial space, connective tissue
intestinalis	belonging to the intestines
Intestinum	intestine(s)
intimus	innermost
intra-	within
Intumescentia	intumescence
Involutio	involution
Iris	iris
ischiadicus	belonging to the ischium
Ischium	ischial bone, ischium
Isthmus	isthmus, narrow passage
-itis	ending for the marking of inflammation diseases

J

Jejunus	sober, empty
Jejunum	jejunum
jugularis	belonging to the front side of the neck
Jugum	yoke
Junctura	junction
juvenilis	youthful
juxta-	near (to)

K

Kneme	calf
Kopros	mud
-krinein	cut off
kryptos	hidden
-klast (klaein)	break in pieces
Kyphosis	convex dorsal bending of the vertebral column

L

Labialis	belonging to the lip
Labium	labium, lips in pairs
Labrum	lips unpaired, flews
Labyrinthus	labyrinth
Lac	milk
lacrimalis	belonging to the tears
lactiferus	milk-bearing
Lacuna	lacuna, depression
Lamella	lamella
Lamina	lamina, plate
laryngeus	belonging to the larynx
Larynx	larynx
lateralis	lateral
latissimus	very broad
Latus	flank
latus	broad
Lemma	cover
Lemniscus	lemniscus, ribbon
Lens	lens
lentiformis	lentiform
lepto-	thin, soft
Levator	elevator (muscle)
liber	free
Lien	spleen
lienalis	belonging to the spleen
Ligamentum	ligament
Limbus	limbus, hem(line)
Linea	line
Lingua	tongue
lingualis	belonging to the tongue
Lingula	lingula, small tongue
Liquor	fluid
Lobulus	lobule
Lobus	lobe
longissimus	longest
longitudinalis	longitudinally
longus	long
lucidus	bright shining
lumbalis	belonging to the loin
Lumbus	loins
lumbricalis	earthworm-like
lunatus	luniform, curved
luteus	yellow
Luxatio	luxation
Lympha	lymph
lymphaticus	lymphatic
Lymphonodulus	lymph(atic) nodule
Lymphonodus	lymph node
Lysis	lysis, dissolution
Lyssa	rabies, lyssa of tongue

M

macro-	macro, small
Macula	macula, spot
magnus	great
major	major
malaris	belonging to the cheek
Malleolus	malleolus
Malleus	hammer
Mamma	mamma, mammary gland
mammillaris	nipple-like
Mandare	masticate, grind or chew
Mandibula	mandible
Manubrium	handle
Manus	hand
Margo	margin, edge, border
masculinus	male
Masseter	masticatory muscle
masticatorius	serving the mastication
mastoideus	nipple-shaped
Mastos	udder
Mater	sheath, mother
maturus	mature
Maxilla	upper jawbone
maximus	greatest
Meatus	passage
medialis	closer to the plane of symmetry
medianus	in the middle
medius	lying in the middle
Medulla	medulla
Membrana	membrane, fine skin
membranaceus	membranous
Membrum	limb
Meninx	meninx
Meniscus	meniscus, half moon
mentalis	belonging to the chin
Mentum	chin
Meros	part, piece
Mesencephalon	mesencephalon
Mesenchym	mesenchyme, embryonic connective tissue
Mesenterium	mesentery
meso-	in the middle, between
meta-	after, later
Metacarpus	metacarpus
Metaplasie	metaplasia, transformation of tissue
Metastasis	migration
Metra	uterus
micro-	small, slight
Mictio	urination
minor	smaller
Miosis	contraction of the pupil
mirabilis	miraculous
mobilis	mobile
Modiolus	central pillar of cochlea
molaris	suitable for champing, grinding
mollis	mellow
monos-	alone
Mons	mount
Morbus	disease
mortalis	mortal

motoricus	motile
mucosus	mucous
multi-	many
Musculus	muscle, little mouse
Mydriasis	dilatation of the pupil
Myelos	medulla
myentericus	belonging to the muscles of the intestines
Mylae	molars
Mylo	mandible
Myo	muscle
Myokard	myocardium, cardiac muscle
Myometrium	myometrium, uterine muscle

N

Nares	nostrils
nasalis	belonging to the nose
Nasus	nose
natalis	concerning birth
neo-	new
Necrosis	necrosis
Nephros	kidney
Nervus	nerve
Neurocranium	cerebral cranium
Neuron	nerve cell
niger	black
nodosus	nodular
Nodulus	nodule
Nodus	node
non-	not
Nucha	nape of neck
Nucleus	nucleus
nudus	naked
nutritius	serving the nutrition

O

Obliquus	oblique
obliterans	no longer in use
oblongatus	extended
obturatorius	obturating
obtusus	obtuse, blunt
occipitalis	belonging to the occiput
Occiput	occiput, back of the head
occludens	closing
occlusalis	suitable for closing
Oculus	eye
Odus	tooth
Olecranon	olecranon, elbow
olfactorius	serving the smelling
oligo	small, little, few
Oliva	olive
Omentum	omentum
Omos	shoulder
Omphalos	umbilicus
ophthalmicus	belonging to the eye
Ophthalmos	eye
opponens	comparing, to be opposite
opticus	serving the vision
Ora	margin, border
oralis	belonging to the mouth
orbicularis	circular
Orbita	orbit(al cavity)
orbitalis	belonging to the orbital cavity
Orchis	orchides, testicle, testis
Organum	organ
Orificium	orifice, mouth
Origio	origin
Os	mouth
Os	bone
osseus	osseous
Ossificatio	ossification
Osteogenesis	bone formation
Osteon	osteon, bone
Ostium	orifice, opening, entrance
oticus	belonging to the ear
ovalis	oval
Ovarium	ovary
Ovulation	ovulation
Ovum	egg

P

pachy-	thick, strong
Palatum	palate
pallidus	pale
Pallium	pallium, mantle
Palma	cupped hand
palmaris	belonging to the palm
palpare	palpitate
Palpebra	eyelid
pampiniformis	tendril-shaped
Pancreas	pancreas, salivary gland of the abdomen
pancreaticus	belonging to the pancreas
Panniculus	panniculus, lobule
Papilla	papilla, wart
papillaris	tubercle-like
para-	alongside
Parasit	parasite
Parasympathicus	parasympathetic part of autonomic nervous system
Parathyroidea	parathyroid gland
Paries	wall
parietalis	belonging to the wall
Parotis	parotid gland
Pars	part
parvus	small
Patella	knee-cap
Pecten	pecten
pectoralis	belonging to the pectus
Pectus	chest, breast
Pediculus	pedicle, peduncle, small foot
Pedunculus	stalk
pellucidus	transparent
Pelvis	pelvis
Penis	penis
pennatus	pennate
perforans	penetrating
Pericardium	pericardium, heart sac
Perineum	perineum
Periosteum	periosteum

permanens	permanent
peronaeus	belonging to the calf bone
perpendicularis	perpendicular
persistere	remain
Pes	foot
petrosus	rocky
phago-	food
Phalanx	phalanx, finger or toe bone
pharyngeus	belonging to the pharynx
Pharynx	pharynx, throat
Philtrum	philtrum, labial groove
phlebo-	vein
Phren	diaphragm
phrenicus	belonging to the diaphragm
Phylogenesis	phylogeny of living beings
Pilus	hair
piriformis	pear-shaped
pisiformis	pea-shaped
pius	soft, tender
Placenta	placenta
Planta	sole (of foot)
Planum	plane
Platysma	plate
Pleura	pleura
Plexus	plexus
Plica	fold
Pneuma	breath, air
pneumaticus	aeriferous
podo-	foot
Pollex	thumb
Pons	pons
Poples	back of knee
popliteus	belonging to the popliteal space
Porta	portal
Portio	portion
Porus	pore, passage
posterior	behind
pr(a)e-	before
praeputialis	belonging to the prepuce
Praeputium	prepuce
primordialis	original
princeps	most important
principalis	first
procerus	slender
Processus	process
profundus	deep
prominens	prominent
Promontorium	promontory, foothills
proprius	own
Prosencephalon	forebrain
Prostata	prostate
proximalis	towards the trunk
Psoas	loin
pterygoideus	wing-shaped
Pteryx	wing
Ptosis	sinking of the (eye)lid
Pubes	pubic region
pubicus	belonging to the pubic region
pudendus	belonging to the genitals
Pulmo	lung
pulmonalis	belonging to the lung
Pulpa	pulp, soft tissue
pulposus	pulp shaped, made of soft tissue
Pulvinar	cushion
Punctum	point
Pupilla	pupil
Putamen	putamen, dish
Pyelos	renal pelvis
pyloricus	belonging to the pylorus
Pylorus	pylorus
Pyramis	pyramid

Q

Quadratus	quadrangular
quadriceps	four-headed
quartus	fourth

R

Radialis	belonging to the radius
Radiatio	radiation
radicularis	belonging to the radical
Radius	radius, spoke
Radix	root
Ramus	ramus, branch
Raphe	seam
rectalis	belonging to the rectum
Rectum	rectum
rectus	straight
recurrens	running back
Regio	region, position
Ren	kidney
renalis	belonging to the kidney
resorbere	resorb
respiratorius	serving the respiration
Rete	network
reticularis	reticular
Retina	retina
Retractor	retractor
retro-	back
Rhis, Rhinos	nose
rhomboideus	rhombic
Rima	cleft, fissure
rostralis	rostral
Rotator	turner
rotundus	round
ruber	red
Ruga	wrinkle, ridge
Ruptura	rupture, crack

S

Sacculus	saccule, small bag
Saccus	sac
sacer-	sacred
sacralis	belonging to the sacrum
Saliva	saliva, spittle
Salpinx	uterine tube
sanguineus	bloody
Saphena	saphenous vein
saphenus	hidden
sarko-	fleash

Sartor	tailor
sartorius	belonging to taylor, a muscle that crosses ther front of the thigh
Scala	scala, stairs
scalenus	oblique
Scapula	shoulder-blade
Scapus	shaft
Sclera	clera, hard tunic of the eyeball
Scrotum	scrotum, bag
Scutulum	small shield
sebaceus	sebaceous
Sebum	sebum
segmentalis	subdivided
Segmentum	segment, section
Sella	armchair
Semen	semen
semi-	half
semicircularis	semicircular
semilunaris	semi(-)lunar
seminalis	connected with the semen
seminifer	semen-bearing
sensibilis	sensitive
septalis	belonging to the septum
septicus	affected by germs
Septum	septum, diaphragm
serratus	serrated
serosus	abounding in serum
sesamoideus	sesame-like
sexualis	sexual
siccus	dry
sigmoideus	sigma-shaped
simplex	simple
sinister	on the left(-hand) side
Sinus	sinus
Situs	position
sive	or
Skeleton	skeleton
skolios	kyphotic, bent
Skoliosis	lateral bending of the vertebral column
solaris	sun-like
Solea	sole
solitarius	single
Soma	body
Spatium	space
Sperma	semen
sphaeroideus	sphere-like
Sphaira	sphere
sphenoidalis	wedge-shaped
Sphincter	sphincter
Spina	spine
spinalis	spine-like
spinosus	thorny
spiralis	round, winding
splanchnicus	belonging to the intestines
Splanchnon	intestines
Splanchnocranium	visceral cranium
Splen	spleen
splenicus	belonging to the spleen
splenius	paving-shaped
Spondylos	vertebra
spongiosus	spongy
Squama	squama
squamosus	squamous
Stapes	stirrup
Stasis	standstill, stopping
stellatus	stellate
stenos	narrow
sterilis	sterile
sternalis	belonging to the sternum
Sternum	sternum
Stigma	sign
Stoma	opening, mouth
Stratum	layer
striatus	striate(d)
Struma	goitre
styloideus	styliform
Stylos	style
sub-	under
Subcutis	hypoderm(is)
Substantia	substance, foundation
sudoriferus	containing sweat
Sulcus	groove
super-	over
superficialis	superficial
Sura	calf of leg
suralis	belonging to the calf
suspensorius	suitable for suspending
Sustentaculum	sustentaculum, prop
Sutura	suture
Sympathicus	thoracolumbar division of autonomic nervous system
Symphysis	symphysis, fusion
syn-	together
Synovia	synovial fluid
synovialis	belonging to the synovial fluid
Synthesis	composition
Systole	constricting of the cardiac muscle

T

Tabula	tablet
Tactus	tactile sense
Taenia	t(a)enia, stria
Talus	tibial tarsal bone
Tarsus	hock, ankle
Tectum	roof
Tegmentum	tegmentum
Tela	tissue
Telencephalon	endbrain
temporalis	belonging to the temple
Tempus	temple, time
tendineus	stringy
tendinosus	abounding in tendons
Tendo	tendon
Tensor	tensor
Tentorium	tent(orium)
tenuis	thin
teres	roundish
terminalis	border marking
tertius	third

testicularis	belonging to the testicle
Testis	testis, testicle
Tetanie	muscle cramp
Textus	tissue
Thalamus	thalamus, inner chamber
Theca	theca, case
therapeuein	to heal
thoracalis, thoracicus	belonging to the thorax
Thorax	thorax
Thrombus	blood clot
thyreoideus	scutiform
Tibia	shin-bone
Tonsilla	tonsil
Torsio	torsion
Torus	torus, pad
Trabecula	trabecula
Trachea	trachea
Tractus	tract(ion)
trans-	through
transversalis	across
transversus	running across
trapezius	trapeziform
Trauma	wound
tri-	three
triangularis	triangular
triceps	triple-headed
trigeminus	triple
Trigonum	triangle
Trochlea	trochlea, roll
Trope	change
tropho-	food
Trochos	wheel
Truncus	trunk
Tuba	tube
Tuba auditiva	auditory tube
Tuba uterina	uterine tube
Tuber	(pro)tuber(ance)
Tuberculum	tubercle, small protuberance
Tubulus	tubule, small tube
Tumor	growth, intumescence
Tunica	tunic, coat
turbinalis	turbinate(d), spiral, conchal
tympanicus	belonging to the tympanum

U

Ulna	ulna
ultra-	on the other side
umbilicalis	belonging to the navel
Umbilicus	navel
uncinatus	hooked
Unguicula	claw
unguicularis	belonging to the claw
Unguis	nail
Ungula	hoof
Urachus	urachus, urinary duct
Ureter	ureter, urinary duct
Urethra	urethra, urinary duct
Urina	urine
Uterus	uterus
Utriculus	utricle
Uvea	(bunch of) grapes
Uvula	uvula

V

Vagina	sheath
vagus	wandering nerve
Valgus	knock-kneed
vallatus	cloaked
Valva	valve
Valvula	valvule, small valve
varus	bow-legged
Vas	vessel
vasculosus	abounding in vessels
vastus	vast
Velum	velum, sail
Vena	vein
Venter	belly
Ventriculus	ventricle, big-bellied room
ventricularis	belonging to the belly
Vermis	vermis, worm
Vertebra	vertebra
vertebralis	belonging to the vertebra
Vertex	crown
verticalis	vertical
Vesica	bladder
Vesicula	vesicle
vesicularis	vesicular
vestibularis	belonging to an anteroom
Vestibulum	vestibule
Villus	villus
Vinculum	band
Vita	life
Vitellus	yolk
vitreus	vitreous
Viscera	viscera
Visus	vision
Vocalis	sounding
Volvulus	torsion
Vortex	vortex

X

Xiphoideus	ensiform, swort shaped

Z

Zele	rupture
Zona	zone
Zonula	zonule, small zone
zonularis	striate(d)
zygomaticus	belonging to the cheek-bone

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